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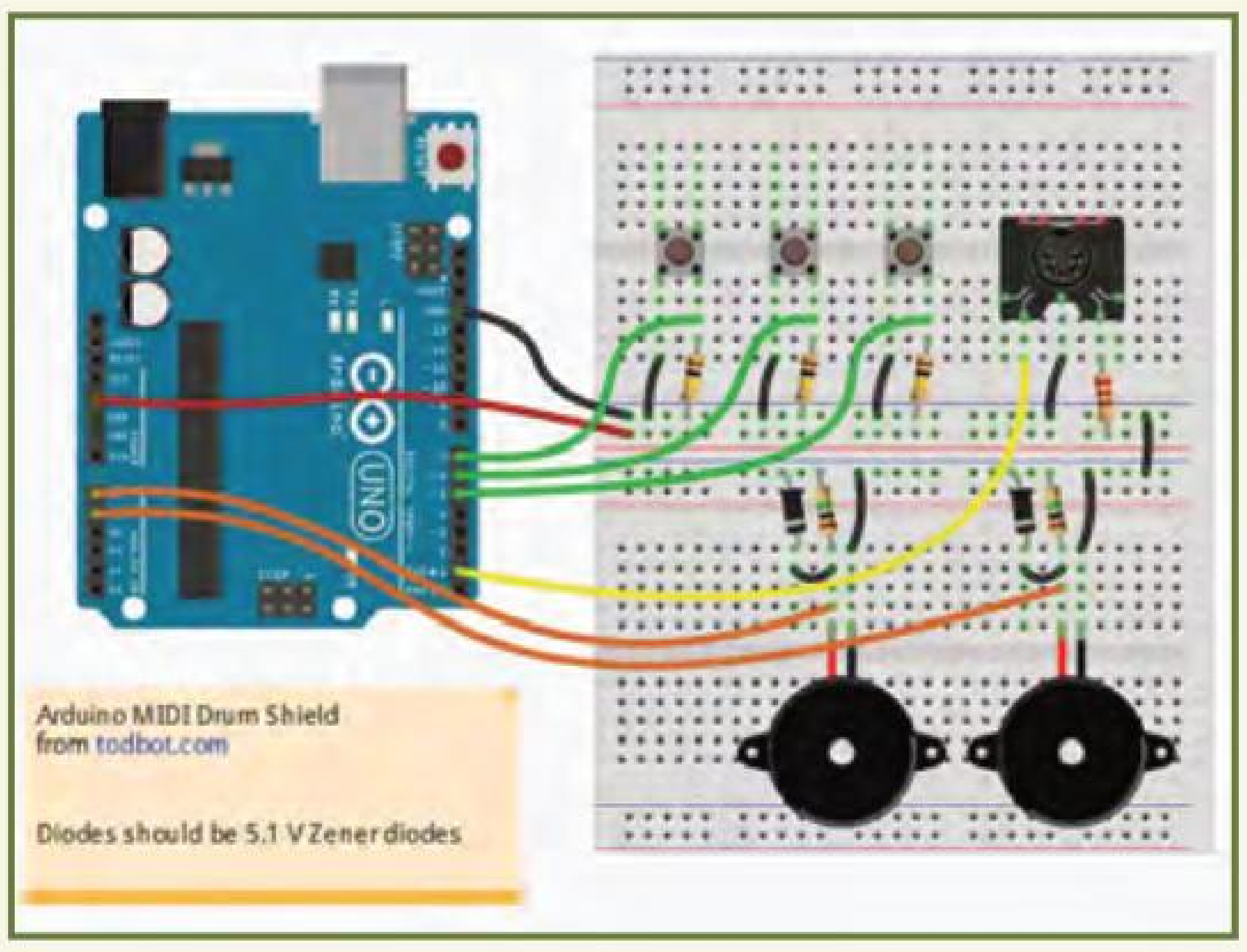

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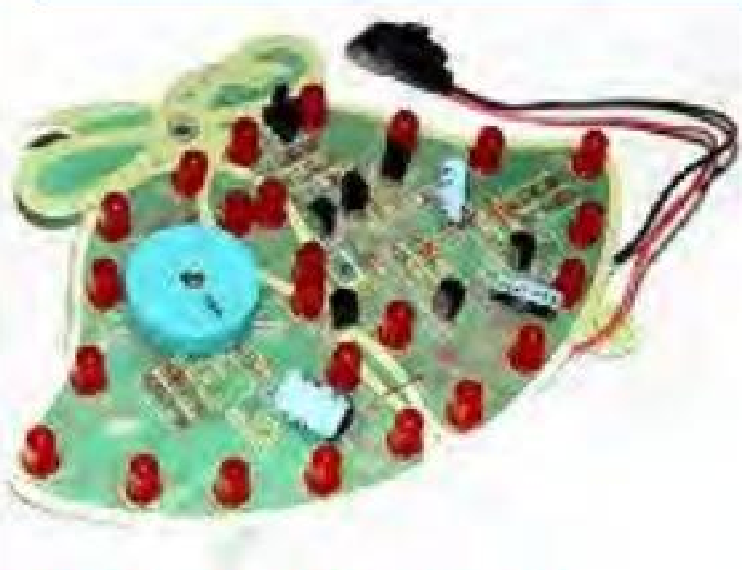

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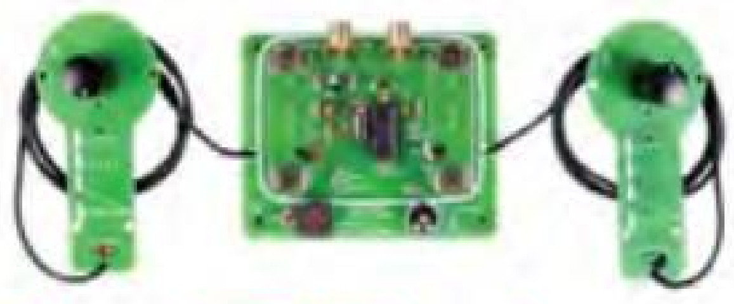

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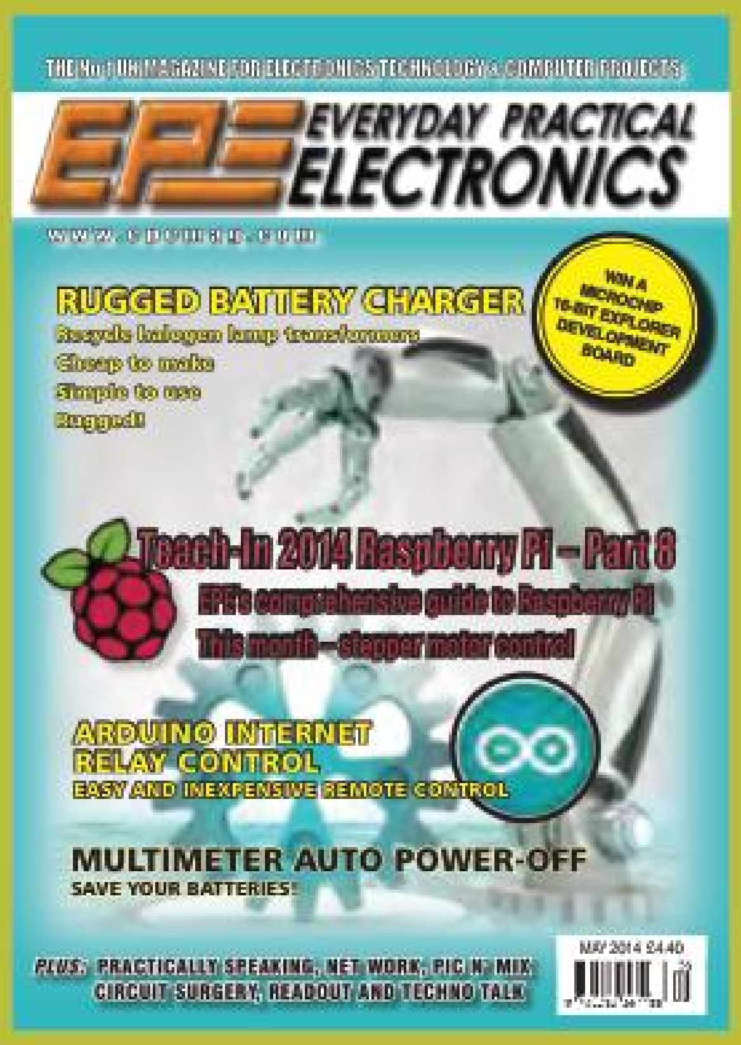
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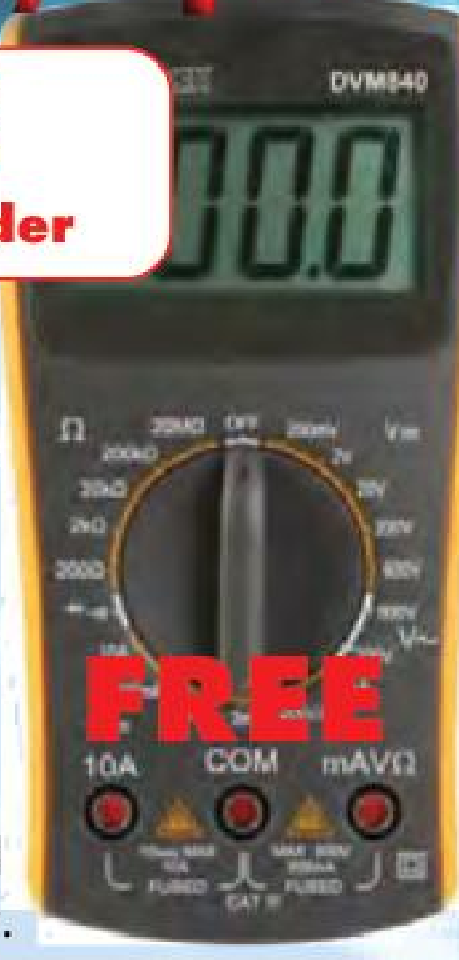

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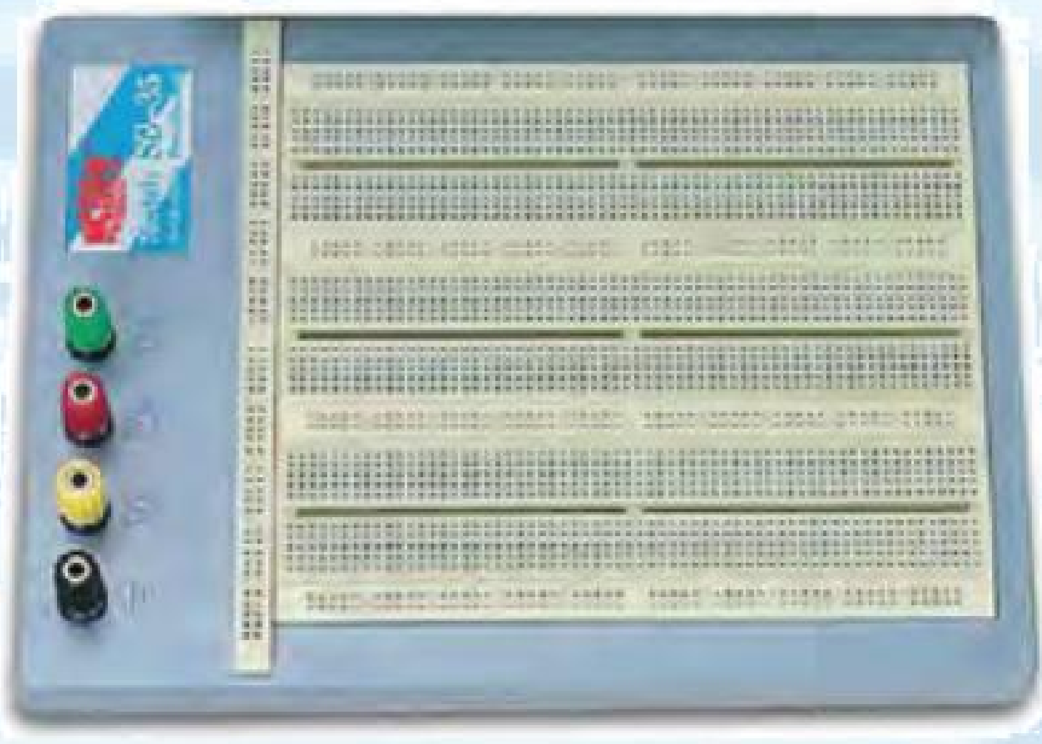

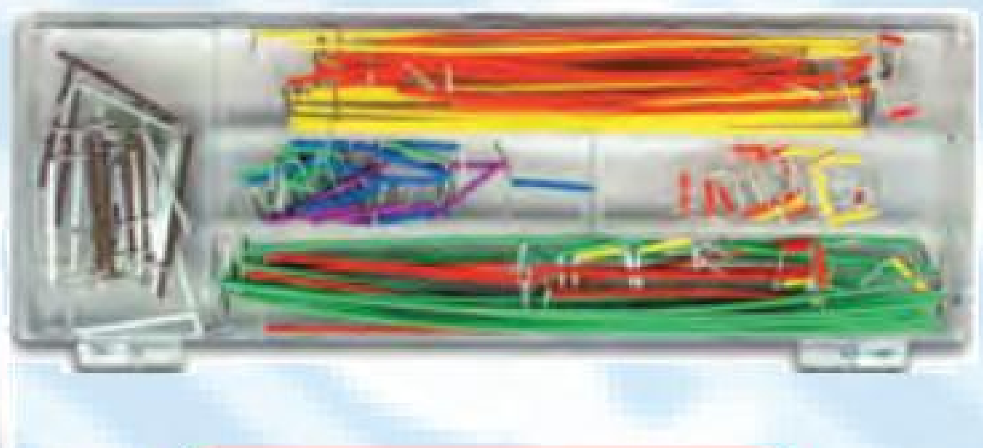

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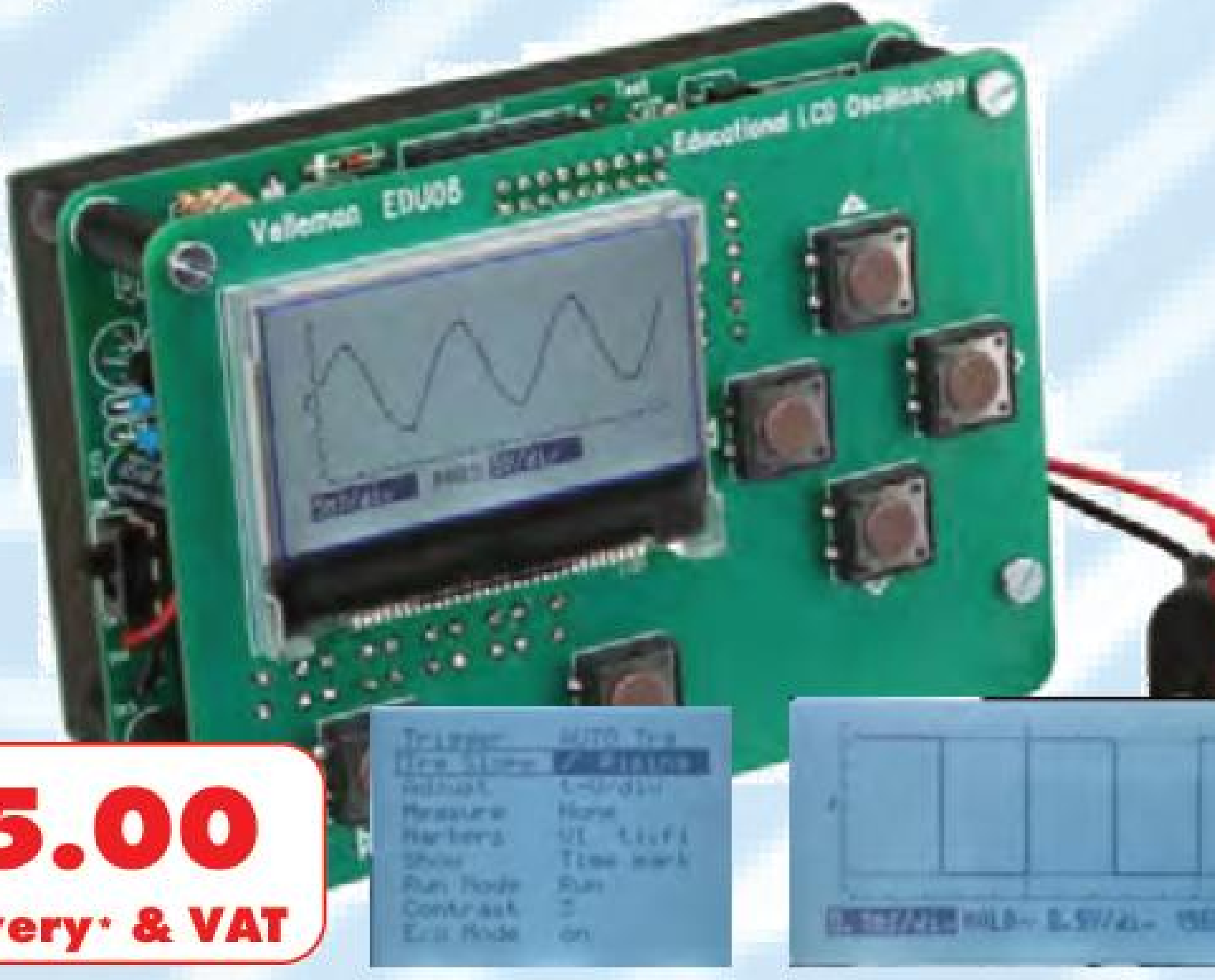

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Seasons greetings

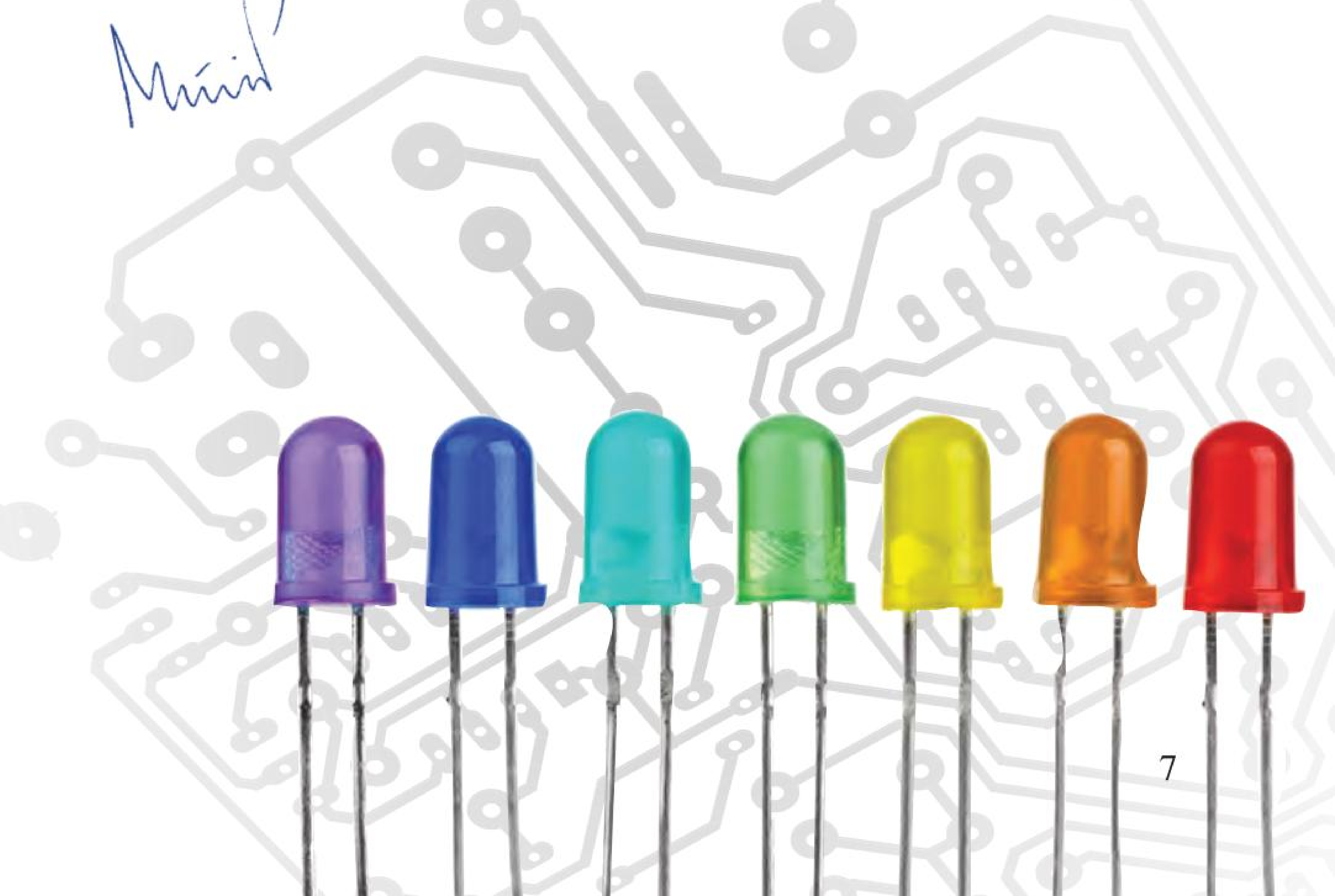
Another year, another dozen issues of *EPE* safely dispatched – where does the time go?! Well, for the hardworking team at Wimborne, a lot of it goes into producing your favourite electronics magazine. It's rewarding work, every day is different and we enjoy hearing from our readers – especially if they have been with us since day 1. Over the last few weeks we have received some fascinating letters (see this month's *Read Out*) following Alan Winstanley's excellent *50 Golden Years of Practical Electronics* articles in the November and December issues. Do take time to read them.

Enough of the past, what of the present and future? Well, we certainly have a packed issue for your Boxing Day reading, and are you tired of hearing the Queen's Speech from those cheap and tinny amp-speaker combos TV manufacturers insist on using? If so, we have just the project for you – the *"Tiny Tim" Stereo Amplifier*; and why not partner it with our excellent *"Tiny Tim" Horn Loaded Speaker System*. (*EPE*, October 2014). Together they make a neat and compact system that sounds terrific and is easy on your wallet. It would even make the perfect Christmas present. If anyone asks, 'what do you want?'; just tell them you'd like funding for the components!

Elsewhere in this issue we have Mike Hibbett's review of an exciting software design package – 'Fritzing'. It's free, easy to use and will certainly help you take your projects to the next level. I strongly recommend you give it a try – and yes, it is available for Linux and OSX users. Now no one has any excuse not to dip a toe into CAD waters!

In *Net Work*, Alan Winstanley has been busy looking at automotive data collection/use with a surprisingly cheap (but powerful) OBD II transmitter. (It's another top idea for a stocking filler.) Diacs and triacs are covered in Ian Bell's *Circuit Surgery* and Mike Tooley reveals more about the latest incarnation of the Raspberry Pi computer – the B+ Model. Regular columnists Jake and Max return from a month's 'leave' and… well you get the picture! Another packed issue to keep you going through to the next issue in January.

So, from all of us at Wimborne, we wish you a very happy Christmas and a fantastic New Year.



NEWS

A roundup of the latest Everyday News from the world of electronics

Berlin Spy Stories: Part 2 – report by Barry Fox

Edward Snowden opened our eyes to the significance of those huge radar spy domes you see on heavily guarded hilltops. What are they like inside?

The Devil's Mountain

I was able to find out by playing truant from the annual IFA electronics 'gadgetfest' in Berlin to brave the wild boar that roam the Grunewald Forest, and trekked several un-signposted kilometres to Teufelsberg or 'Devil's Mountain'.

This is an artificial mound, 120m high and very steep. It was built by the allies over a period of 20 years from 1950, by daily dumping hundreds of lorry loads of World War II rubble. One object was to bury Albert Speer's Military College, which like the concrete Rally Stadium in Nuremberg, near Grundig's HQ, was just too solid to blow up.

Initially, the mount was covered with trees and a ski slope. Then, in the early 1960s, the National Security Agency built tall towers and radomes (a portmanteau word formed from radar and dome) on the top to spy on the East. The ski lifts were demolished because their cables interfered with radio reception.

From eavesdropping to graffiti

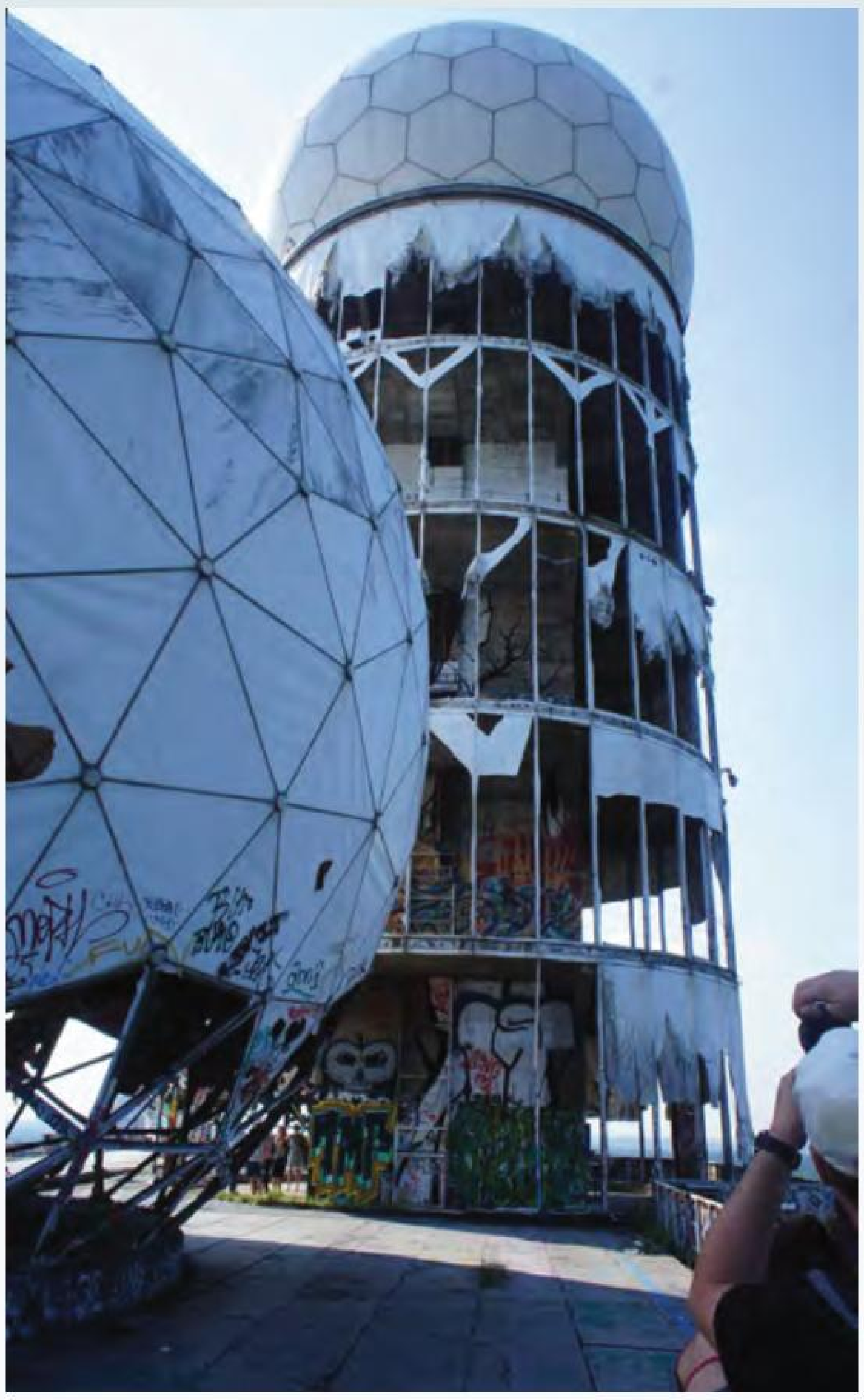
When the Cold War ended, the Americans left Teufelsberg, and property developers got permission to build luxury apartments with stunning views. But they gave up on the plan and the derelict site was sold to young German entrepreneurs who have now thrown it open to graffiti artists, a hippie commune and curious visitors. Trees have grown all around the site but the topmost radomes can still sometimes be glimpsed from many miles away.

Cold War mass storage was a real problem – as late as 1986 a one-megabit RAM chip (not even one megabyte) from Matsushita was a noteworthy technical triumph.

The triple wire fencing round the site no longer has guard dogs running between the enclosures, or armed guards. But it is still tightly locked up. One reason is that some of the graffiti is extraordinary art and now needs protection from inferior graffiti.

'We are running out of wall space' explained one of the young Germans who now show visitors round the site, by appointment and – so far at least – with surprisingly low-key publicity. I discovered the opportunity largely by chance.

But why is such a huge site running out of wall space; and why did the property developers give up? There is a single answer to both these questions – and you won't find it in Wikipedia.



The now slightly tatty polyhedral radomes at Teufelsberg, just outside Berlin in eastern Germany

Mass storage

In Cold War times there was no computer mass storage to cope with the vast amount of snoop data being collected. As late as 1986, it was a big deal when Japanese giant Matsushita/Panasonic announced a one-megabit chip for use in home video equipment. So everything on the mountain was printed to paper, or sent by teleprinter. Because West Berlin was a land-based island in the middle of East Germany, all the paper had to be burned on site after reading. For fire safety the enormous storage and incinerator buildings were thick with asbestos.

Clearing the site of asbestos proved just too expensive, with the fear of crippling law suits if any dust leaked out and down into Berlin. The storage and incinerator buildings are now tightly sealed.

Fortunately, the main radome tower was cleared to build a now graffiti-covered show flat, and it is safe to enter, as long as you are careful not to fall off the edges or down the disused lift shafts.

Radomes

So what is it like inside a radome? It's huge, of course, like the inside of a giant football. The top dome at Teufelsberg is solid, rather than inflated. The big surprise, though, is the acoustics. Being perfectly spherical the walls reflect and amplify sound so efficiently that a handclap takes at least five seconds to decay.

How long, I wondered, will it be before one of the *avant garde*, percussion-heavy, rock groups that flourish in Germany gets the idea of recording there. The sound would be like Armageddon, only louder.

The Teufelsberg structures have gone from housing cutting-edge security equipment to large-scale graffiti artworks

Computer conservation awards

The 2014 Tony Sale Award for computer conservation has been jointly awarded to two outstanding and contrasting entries representing computing in the 1930s and 1950s.

The winners are the IBM 1401 Demo Lab, a restoration of one of the most significant machines in computer history by the Computer History Museum in Mount View, California; and Z1 Architecture and Algorithms, a virtual reconstruction of the 1930s Konrad Zuse mechanical computer, by the Free University of Berlin.

Run by the Computer Conservation Society (CCS) and sponsored by Google UK, this is the second Tony Sale Award for computer conservation. The first was won in 2012 by Dr David Link for 'LoveLetters', a computer art installation.

IBM 1401 Demo Lab

The IBM 1401 Demo Lab is a classic reconstruction of a 50-year-old commercial computer. It marked the transition of IBM as a supplier of accounting machines to it becoming the dominant supplier of the mainframe era. Announced in 1959, the IBM 1401's success took everyone by surprise. The company had expected to sell or lease about 1,000, but went on to deliver 15,000 and by the mid-1960s they amounted to half of the computers in the world. Its high-speed chain printer was a key to its success – punched card machines were eagerly traded in for the IBM 1401 and business computing took a huge stride forward.

In a project involving 20 volunteers over ten years, two 1401s have been restored at the Computer History Museum. The computers and ancillary equipment, including the 1403 chain printer, are on permanent display and run twice a week – for more information, see: **www.computerhistory.org/atchm/restoring-the-ibm-1401**

Z1 – a virtual restoration

Z1 Architecture and Algorithms, the other joint-winner, is a virtual reconstruction of one of the world's earliest computers, the Z1. Originally built in 1936-38, it was destroyed in a bombing raid in 1943. In the 1980s and then in his 70s, Konrad Zuse embarked on a reconstruction of the Z1, which is now a remarkable but static exhibit at the Technology Museum in Berlin. However, with 30,000 parts the reconstruction of the mechanical computer was unlikely to be robust or reliable enough for regular operation, so a team led by Professor Raul Rojas began a virtual reconstruction with a technical description.

Through meticulous research, Professor Rojas and his team made a 3D simulation of the arithmetic unit for deployment on the web. In addition, hundreds of high-resolution photos of the Z1 enable web users to explore the machine from any angle – see **http://zuse-z1.zib.de**

Heritage

Rachel Burnett, Chair of the CCS, said 'The late Tony Sale would have been delighted with the entries that we have had in the year of the silver jubilee of our Society that he co-founded with Doron Swade.

'The computer conservation movement is dynamic and growing apace. Through the Tony Sale Award, we salute the computing pioneers of the past and the dedication of those today who breathe vibrant life into our incredible computing heritage.'

Eliminating poor mobile coverage...

Stuck in a mobile deadzone? As part of its long-term economic plan, the Government has set out plans to eliminate the poor mobile coverage that blights a fifth of the UK.

These areas – so called 'partial not-spots' – have coverage from some but not all of the four mobile networks (EE, O2, Three and Vodafone). Depending on the network consumers are on, they therefore may have no coverage.

Talks have been held with the mobile companies in recent months in an attempt to find a voluntary solution and this work by the industry is expected to continue while the consultation runs.

... building up free Wi-Fi

Over 1000 public buildings in cities across the UK will be transformed into free Wi-Fi hotspots.

Over the coming months, libraries, museums, civic centres, transport hubs, sporting complexes and other buildings around the UK will begin to offer free Wi-Fi – some have already gone live, and the remainder are all on track to be up and running by March 2015.

Anyone with a Wi-Fi-enabled device will be able to take advantage of free connectivity across the UK, which in turn will support cities in becoming even more attractive places to live, do business, visit and invest in.

The project is part of the Government's £150m SuperConnected Cities programme aimed at transforming the digital capability of UK cities, ensuring UK cities boast world-class connectivity and are equipped to deal with the increasing demands of the digital age.

CatNav

According to pet-tech organisation G-Paws, 'the daily question every owner asks their pet, "where have you been kitty?" is no longer rhetorical', thanks to their pet tracker. The unit is a simple collar GPS data logger that gives owners a better insight into the lives of their animals. For more information, visit: **http://g-paws.com**

STANDBY
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A low cost, high-quality audio amplifier – ideal for flat panel TVs, MP3s and more!

Part 1

Leo Simpson and Nicholas Vinen

"Tiny Tim" Stereo Amplifier

Most flat panel TVs have mediocre sound quality from their tiny inbuilt downward firing loudspeakers. So how do you get get better sound? The short answer is that you need a good quality stereo amplifier with either a Toslink or S/PDIF digital input and some decent speakers. Our solution is the 'Tiny Tim', with around 10W per channel and digital inputs.

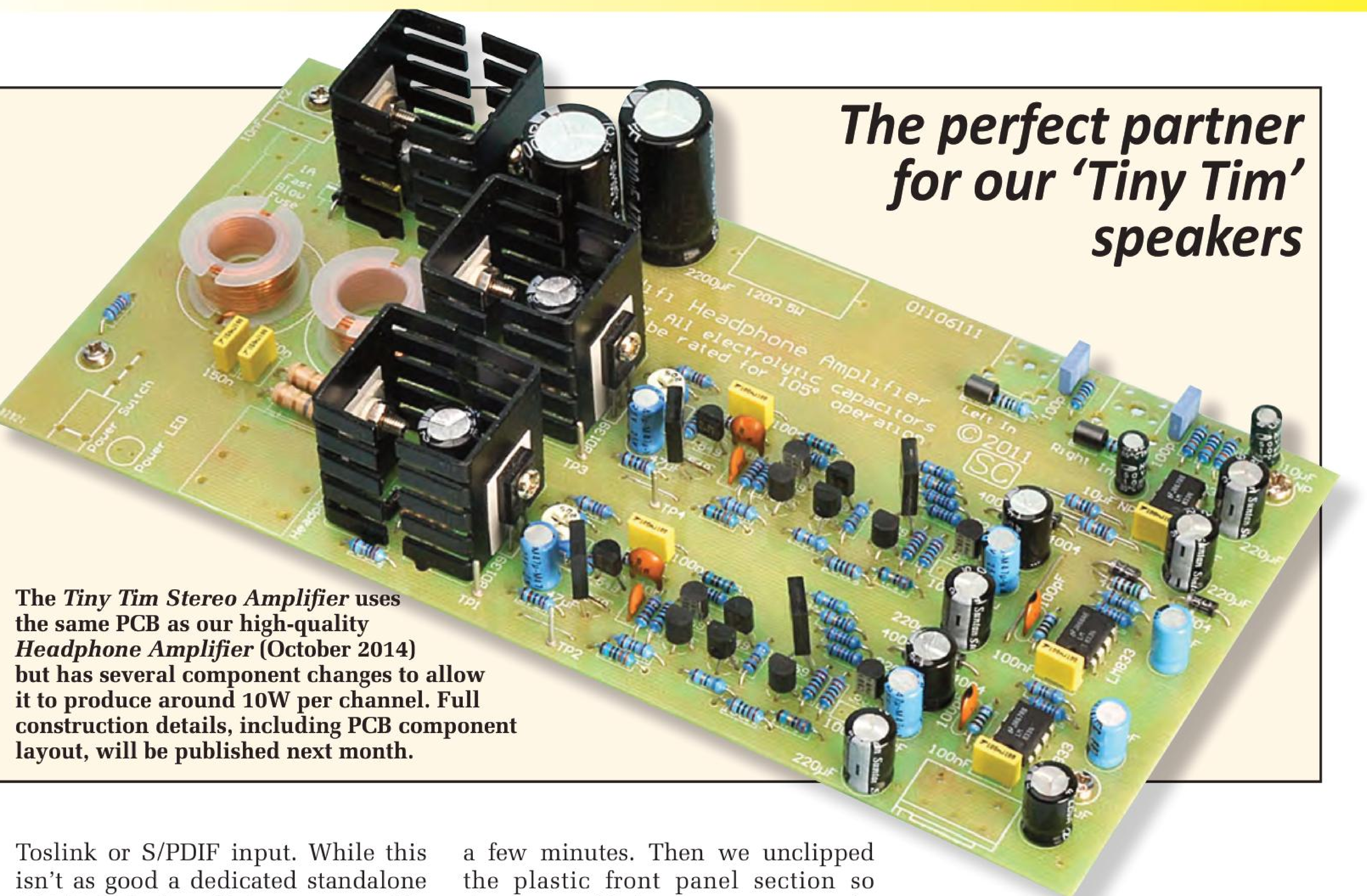
Back in our October 2014 issue we featured the *Tiny Tim Loud-Speaker System,* which is based on a 4-inch wide-range driver in an unusual horn-loaded cabinet. It only requires modest power to drive it to more than adequate sound levels.

Combined with the amplifier described here, it is ideal for for TV viewing or for a high quality music system in a small living room, study or bedroom.

We also published the high quality *Headphone Amplifier* in that issue, and we did indicate that it could comfortably drive 8Ω loads to quite respectable power levels – more than 4W, at very low distortion. However, it was only equipped with a front panel headphone socket, so you would have to use some sort of cable adaptor to connect the speakers to the socket. As a result, very few readers have probably bothered to do so, but simply used it with just headphones. That is unfortunate because it really is a very good performer.

So, part of the reasoning behind this project is to give the headphone amplifier a boost in power output to around 10W per channel while still retaining its very low distortion. At the same time, we are teaming it with a compact commercial DAC (digital-to-analogue converter) to provide the required

The perfect partner for our 'Tiny Tim' speakers



The *Tiny Tim Stereo Amplifier* uses the same PCB as our high-quality *Headphone Amplifier* (October 2014) but has several component changes to allow it to produce around 10W per channel. Full construction details, including PCB component layout, will be published next month.

Toslink or S/PDIF input. While this isn't as good a dedicated standalone Hi-Fi DAC, it still has respectable performance while being significantly cheaper and much more compact.

Elsewhere in this article are the performance specifications of the completed amplifier and a number of graphs illustrating its frequency response, harmonic distortion versus frequency and so on.

Compact case

One of the problems we have with presenting small projects such as this is sourcing suitable small cases which look good and are not expensive.

For this project, we are taking the recycling approach and it involves using the case from a digital set top box which recently failed. The compact case is a good size and readily accommodates the headphone amplifier PCB, a small DAC and a 30VA (or 20VA) toroidal power transformer.

No doubt other cases from compact DVD or CD players could also be pressed into service. In fact, some readers might take the approach of buying a set top box and removing the innards, just to get a cheap metal case.

Either way, you should be able to use some of the existing hardware such as the power cord and power switch. That is what we were able to do.

We removed the existing PCBs from the STB case, a job which only took a few minutes. Then we unclipped the plastic front panel section so that we could do some surgery to it. This involved cutting away a section which was evidently provided for a model with some sort of card reader. We needed to do this as it would otherwise have interfered with the amplifier PCB. We also wanted to remove all of the existing screen-printed labelling. This was a matter of judicious cleaning with mineral turps. This slightly dulled the shiny finish of the panel – but that was easily restored with a light car polish.

We then installed a dual gang volume control and a 6.5mm stereo headphone socket. This socket would allow headphones to be used instead of loudspeakers with automatic switching to turn the speakers off if a headphone jack plug was inserted. We also added an LED as a power indicator.

Main Features

- **Easy to build**
- **Uses common, low-cost parts**
- **Suits 4-8Ωspeakers, 8-600Ω headphones and ear buds**
- **Very low distortion and noise**
- **Short-circuit protected**

Specifications *(bandwidth 20Hz-22kHz unless otherwise stated; see Figs.1-4)*

Output power, 8Ω (THD+N < 0.01%): 2 × 8W
Output power, 4Ω (THD+N < 0.01%): 2 × 6.5W
Music power, 4Ω/ 8Ω: 10W
THD+N: <0.0006% @ 1kHz/1W
Signal-to-noise ratio: –120dB unweighted with respect to 10W
Frequency response: ±0.15dB, 20Hz-20kHz
Channel separation: 100dB @ 100Hz, 83dB @ 1kHz, 63dB @ 10kHz

NB: Power measurements made with a 20VA toroidal power transformer; the alternative 30VA transformer would be expected to produce slightly higher power figures.

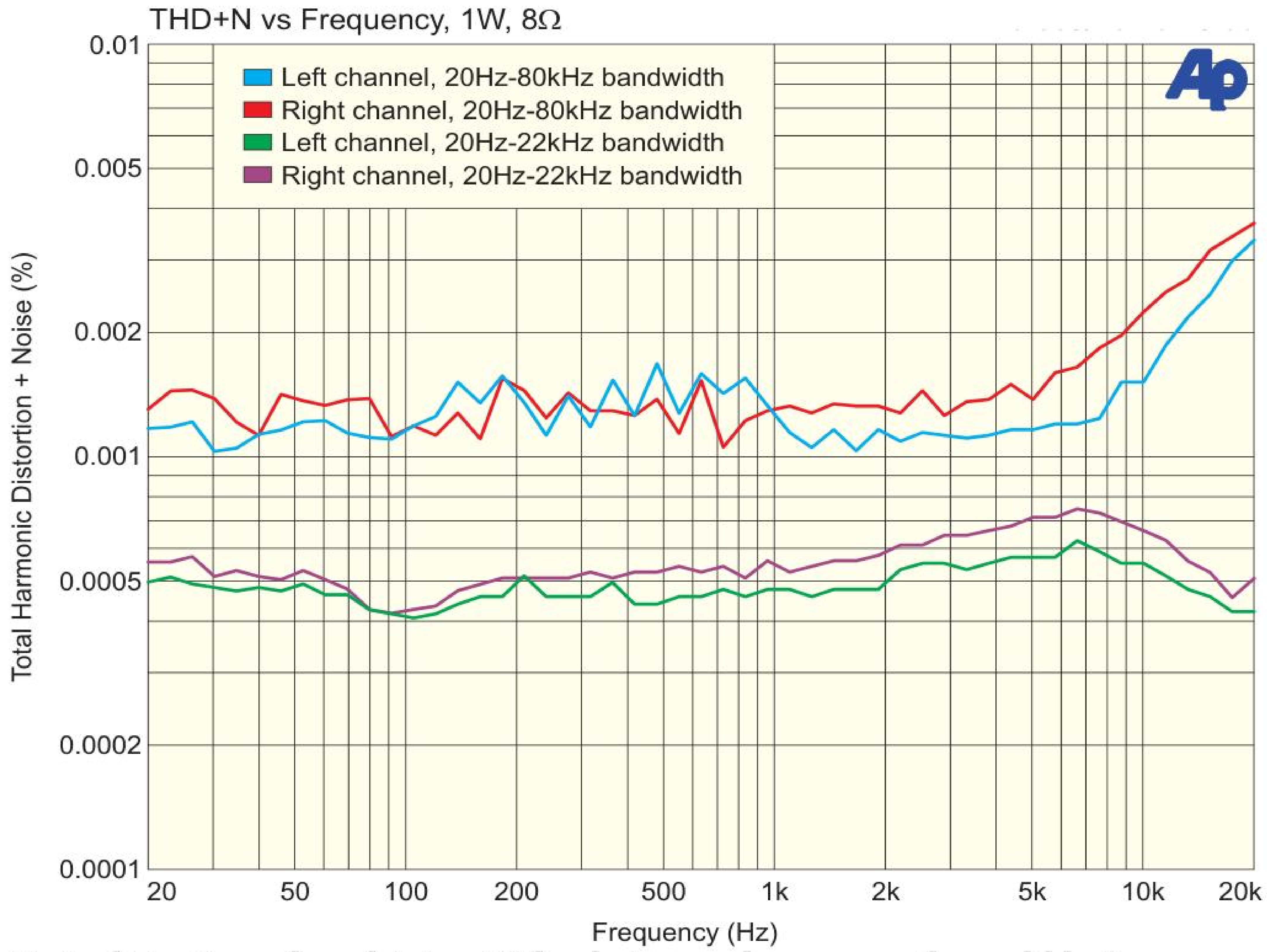


Fig.1: distortion when driving 8Ω loads is very low across the audible frequency range. The two lower curves include a realistic noise level, however, they do not show the rising distortion with frequency. The upper two curves do show this but the inaudible noise between 20kHz and 80kHz increases the overall readings.

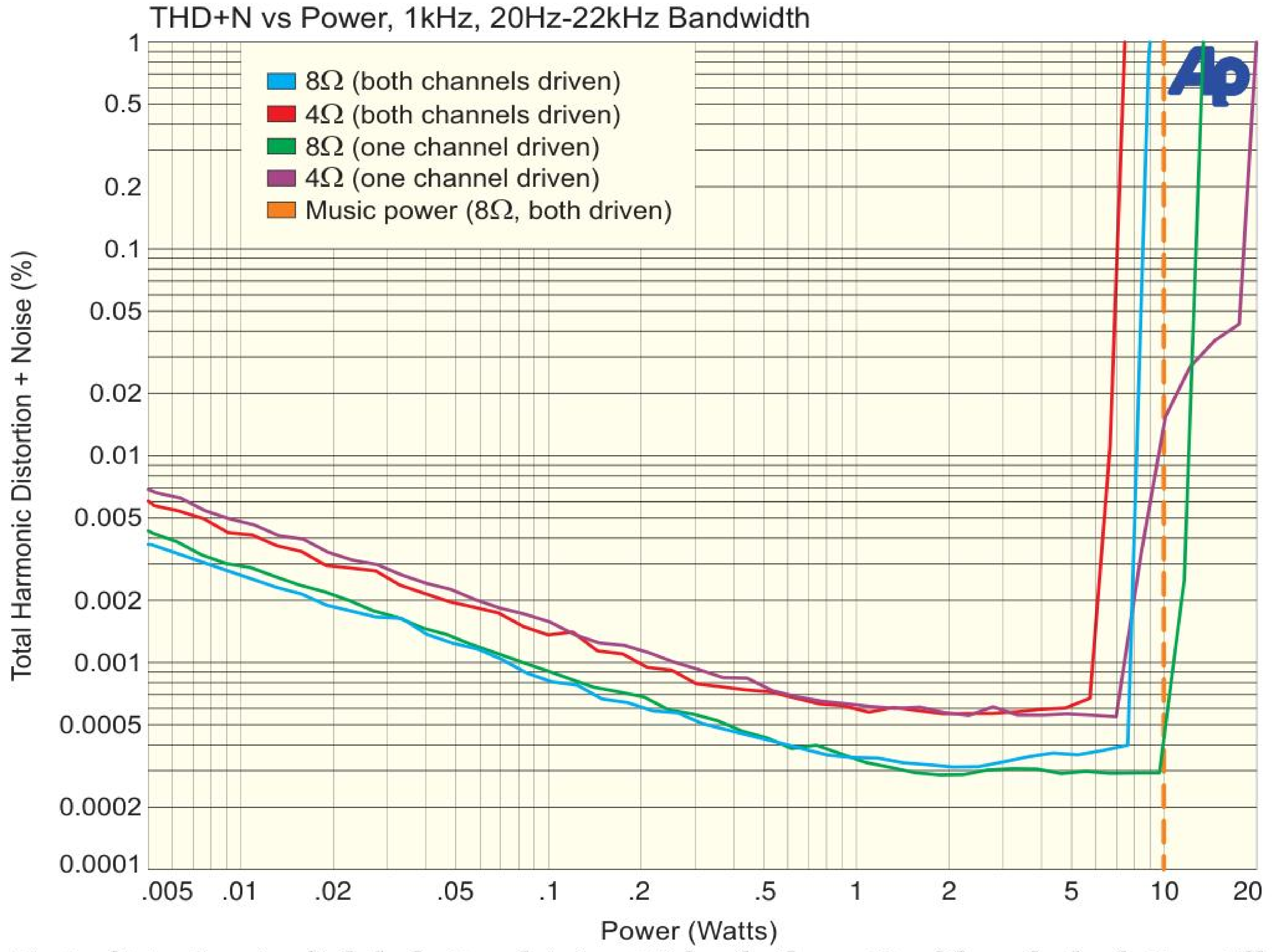


Fig.2: distortion is slightly better driving 8Ω loads than 4Ω, although the latter still gives a respectable result. Distortion drops with level as the signal increases above the noise until the onset of clipping. Slightly more power is available with one channel driven than both due to power supply limitations (20VA transformer used).

Inside the case we have mounted the PCB for the above-mentioned amplifier, the compact DAC and a 20VA toroidal power transformer plus a rectifier and filter capacitors on a small secondary board. However, before describing the internal details, we need to describe the modified headphone amplifier circuit.

Modified headphone amplifier

The main changes to the circuit involve the just-mentioned transformer, which is part of a beefed-up power supply in place of the original 12VAC 1A or 2A plugpack. Briefly, the other changes include increasing the capacitance of the power supply filter capacitors; increasing the voltage rating of other electrolytic capacitors from 25V to 50V, increasing the drive to the output transistors and increasing the gain of the power amplifiers.

Rather than just describe the changes, we will give details of the complete circuit, for the benefit of readers who may not have seen the article in the Ocotber 2014 issue.

Fig.5, the complete circuit, shows both channels. It is split into two sections, with the preamplifiers and power supply on the left-hand side and the power amplifiers on the right-hand side.

The preamplifier for each channel is based on three op amps in a classic Baxandall design, so three LM833 dual op amps are used. The preamplifier is inverting and has a gain range from zero to –7.

The Baxandall preamplifier circuit has the advantage that it varies its gain according to the setting of potentiometer VR1. As a result, the residual noise level is kept low at the low gain settings most commonly required. Like a traditional preamplifier, its gain can go all the way down to zero and up to some fixed number, in this case –7, with the minus sign indicating that it inverts the signal.

The two power amplifiers on the right-hand side of the circuit are very similar to the *20W Class-A Amplifier* (*EPE*, October, November and December 2008) but with smaller output transistors and tiny heatsinks. The power amplifiers invert the signal again, so the unit's outputs and inputs are in-phase. Since there is so much gain available in the preamps, the power amplifiers operate with low gain, (ie, –1.83). This improves the noise performance and maximises the feedback factor, keeping distortion exceedingly low even with run-of-the-mill output transistors.

Since the headphone connector is a jack socket, the outputs can be briefly short-circuited by the plug if it is inserted or removed during operation. Because of this possibility, the design incorporates short-circuit protection to prevent any damage.

Common-mode distortion

By lowering the gain, we get a higher feedback factor (which is good) but we also increase the possibility of common-mode distortion. This can reduce the effectiveness of a high feedback factor so that the distortion reduction (due to the feedback) is not as much as would otherwise be the case.

While the differential input voltage (ie, the voltage between the two inputs) of an amplifier operating in closed-loop mode is very small, both input voltages can still have large swings, especially when the amplifier is being driven hard. This is the 'common-mode' signal, ie, signal common to both inputs.

For a non-inverting amplifier, the common-mode voltage is the output voltage swing divided by the closed-loop gain. So at low gain, the common-mode signal amplitude is similar in magnitude to the output signal amplitude, which for our amplifier can be around 28V peak-to-peak. Typically, if the common-mode signal exceeds 1-2V RMS, common-mode distortion can become the dominant distortion mechanism, marring its performance.

This is due to 'Early effect' in the input transistors (named after James Early of Fairchild Semiconductor). This is caused by the effective width of the transistor base junction varying with its collector-base voltage (**wikipedia.org/wiki/Early_effect**).

If the common-mode voltage is large enough, the result is modulation of the input transistors' beta (or gain) and this reduces the overall linearity of the amplifier. These non-linearities cannot be corrected by negative feedback since they occur in the input stage.

The solution is to use an inverting amplifier, as we have here. Its non-inverting input is connected to ground, so the inverting input is held at 'virtual ground' too, regardless of the output voltage. This configuration has so little common-mode voltage that it can't suffer from common-mode distortion.

To make a power amplifier inverting, we rearrange the feedback network in the same manner as we would with an op amp. In fact, common-mode distortion in op amps can be reduced using the same method.

The main disadvantage of the inverting configuration is that the input impedance is low, as determined by the resistor from the signal source to the inverting input. For good noise performance, its value must be low (minimising its Johnson-Nyquist thermal noise – again, see **www.wikipedia.org/wiki/Johnson_nyquist_noise**). In this case, the preamplifiers provide the amplifiers with a low source impedance, so it isn't a problem.

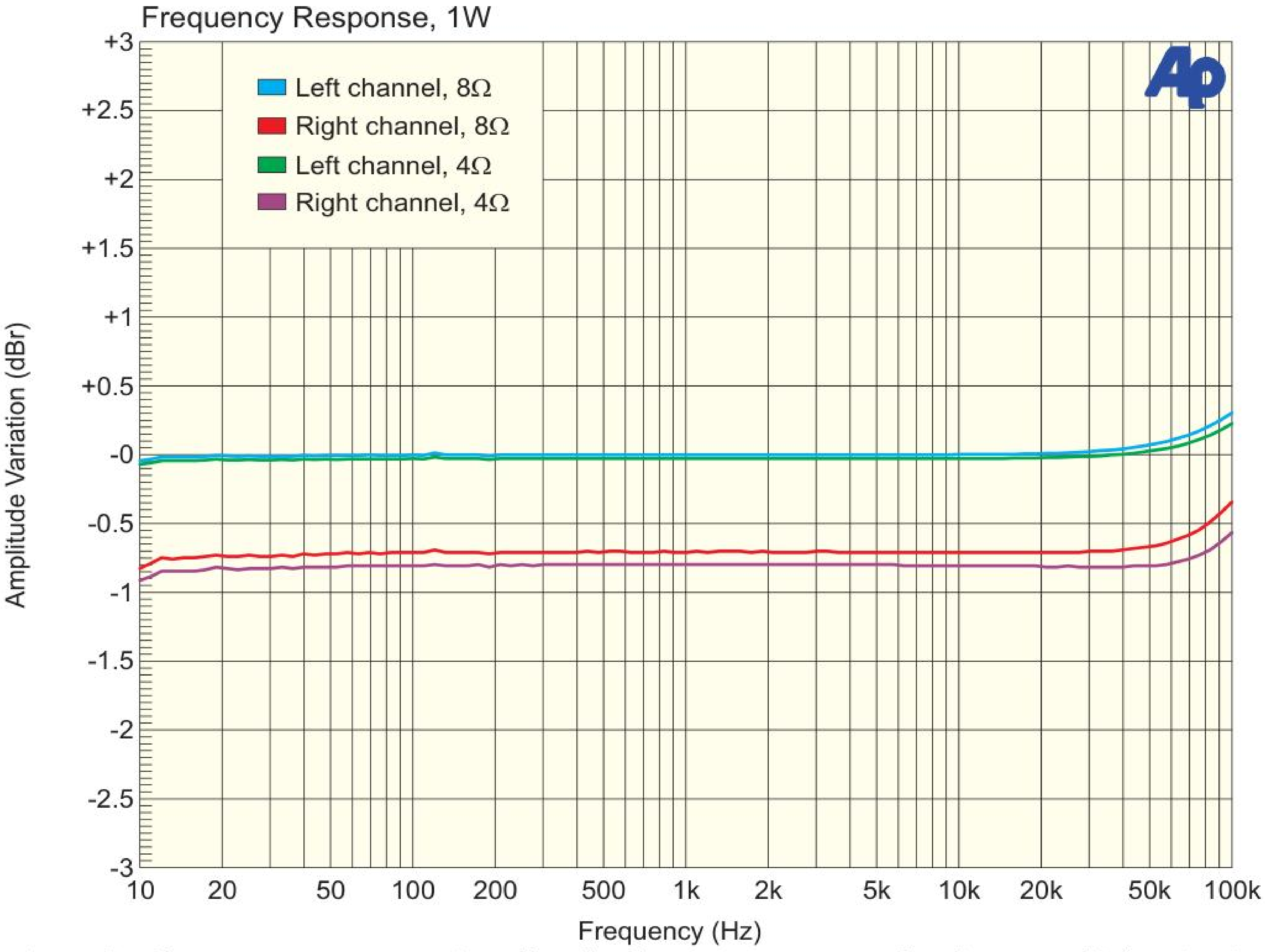


Fig.3: the frequency response is ruler-flat between 20Hz and 20kHz. A slight rise is evident above 20kHz due to the RLC output filter, however, this drops off at frequencies above 100kHz (not shown). The difference in left and right channel level is due to the tracking error in the pot, which is less than 1dB across much of the range of the pot.

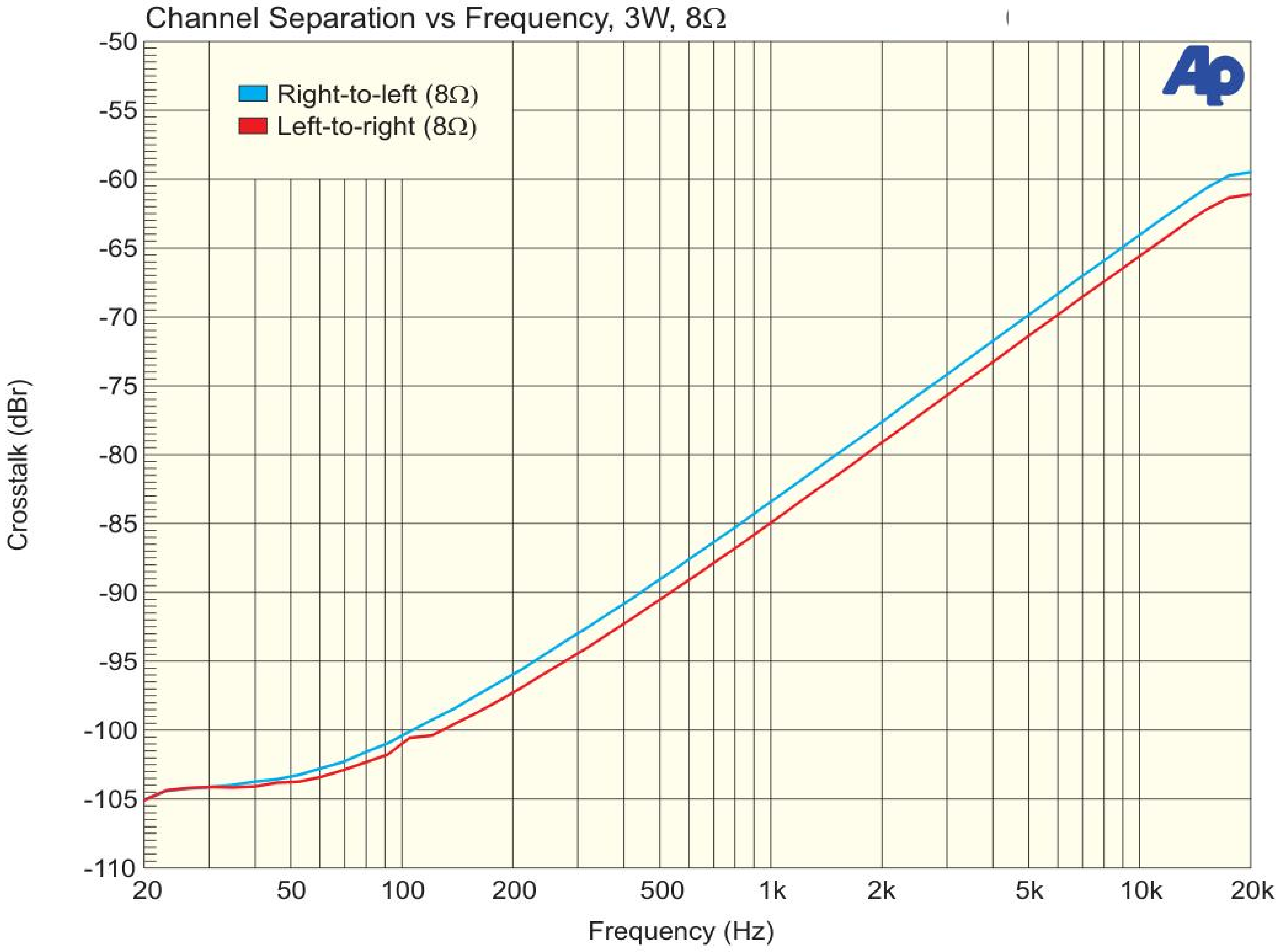
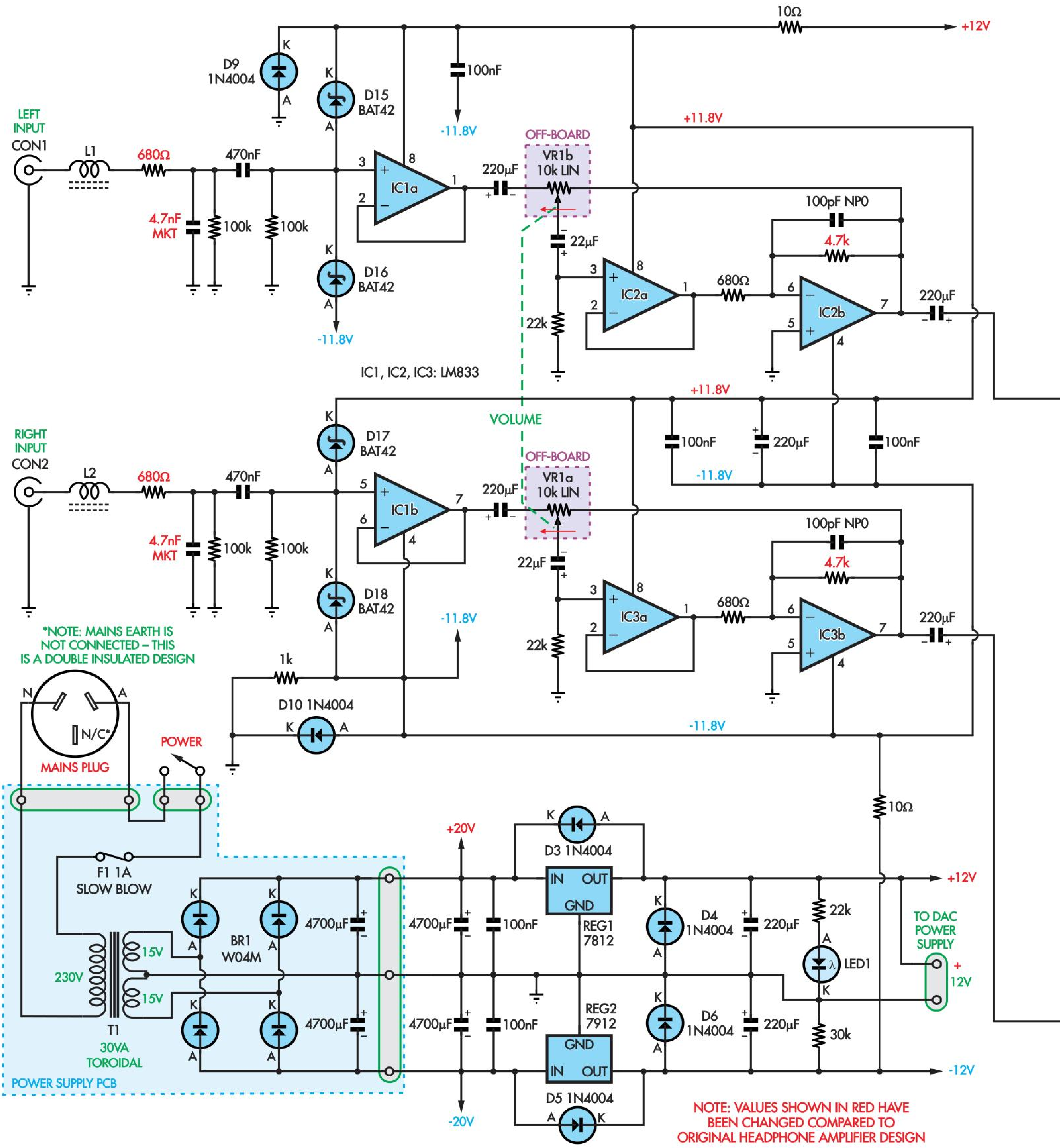


Fig.4: channel separation vs frequency, with a higher value being better. This is better driving speakers (shown here) than headphones because speakers do not have a shared ground return path. The coupling between channels is mostly capacitive, hence separation is better at lower frequencies.

No driver transistors

If you compare the amplifier circuits to our previously published amplifier designs such as the *20W Class-A Amplifier*, you will find many similarities.

This design uses 2-pole frequency compensation, as a result, the *Tiny Tim Amplifier* has particularly low distortion at high frequencies.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100k
100pF NP0
4.7k
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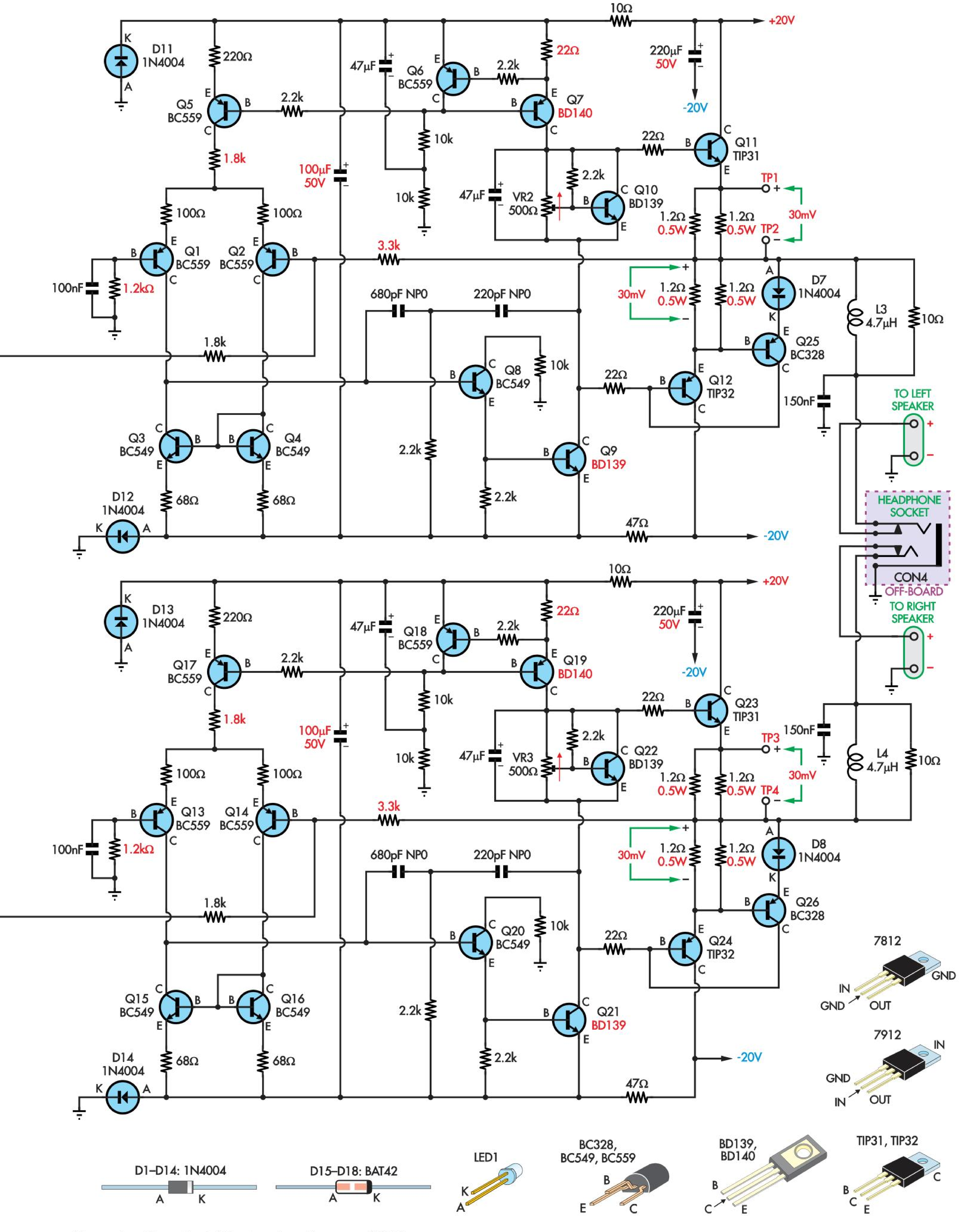
NOTE: VALUES SHOWN IN RED HAVE
BEEN CHANGED COMPARED TO
ORIGINAL HEADPHONE AMPLIFIER DESIGN

TINY TIM 10W STEREO AMPLIFIER

Fig.5: The full circuit for the *Tiny Tim Amplifier*, including the mains power supply (lower left) which is built on a separate PCB. The onboard preamp is shown at upper left and this provides gain control and buffering to drive the power amplifiers, at right. These are based around a TIP31/TIP32 complementary transistor pair without driver transistors, driven by a more-or-less conventional front end. The supply voltage has been increased compared to the original headphone amplifier design and some of the component values have been changed to increase gain and current delivery, hence available power.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Q7
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-20V
10k
10k
100μF
50V
Q11
TIP31
TP1
TP2
30mV
1.2Ω
0.5W
47μF
VR2
500Ω
2.2k
Q10
BD139
100Ω
100Ω
Q1
BC559
Q2
BC559
3.3k
100nF
1.2kΩ
680pF NP0
220pF NP0
D7
1N4004
L3
4.7μH
10Ω
1.8k
Q8
BC549
10k
22Ω
Q12
TIP32
Q25
BC328
150nF
TO LEFT SPEAKER
Q3
BC549
Q4
BC549
2.2k
Q9
BD139
2.2k
68Ω
68Ω
D12
1N4004
47Ω
-20V
HEADPHONE SOCKET
CON4
OFF-BOARD
TO RIGHT SPEAKER
D13
1N4004
Q17
BC559
Q18
BC559
Q19
BD140
Q23
TIP31
TP3
TP4
VR3
500Ω
Q22
BD139
Q13
BC559
Q14
BC559
D8
1N4004
L4
4.7μH
Q20
BC549
Q24
TIP32
Q26
BC328
Q15
BC549
Q16
BC549
Q21
BD139
D14
1N4004
7812
IN
GND
OUT
GND
7912
IN
GND
IN
OUT
D1–D14: 1N4004
A
K
D15–D18: BAT42
A
K
LED1
K
A
BC328, BC549, BC559
B
E
C
BD139, BD140
B
C
E
TIP31, TIP32
B
C
E
C

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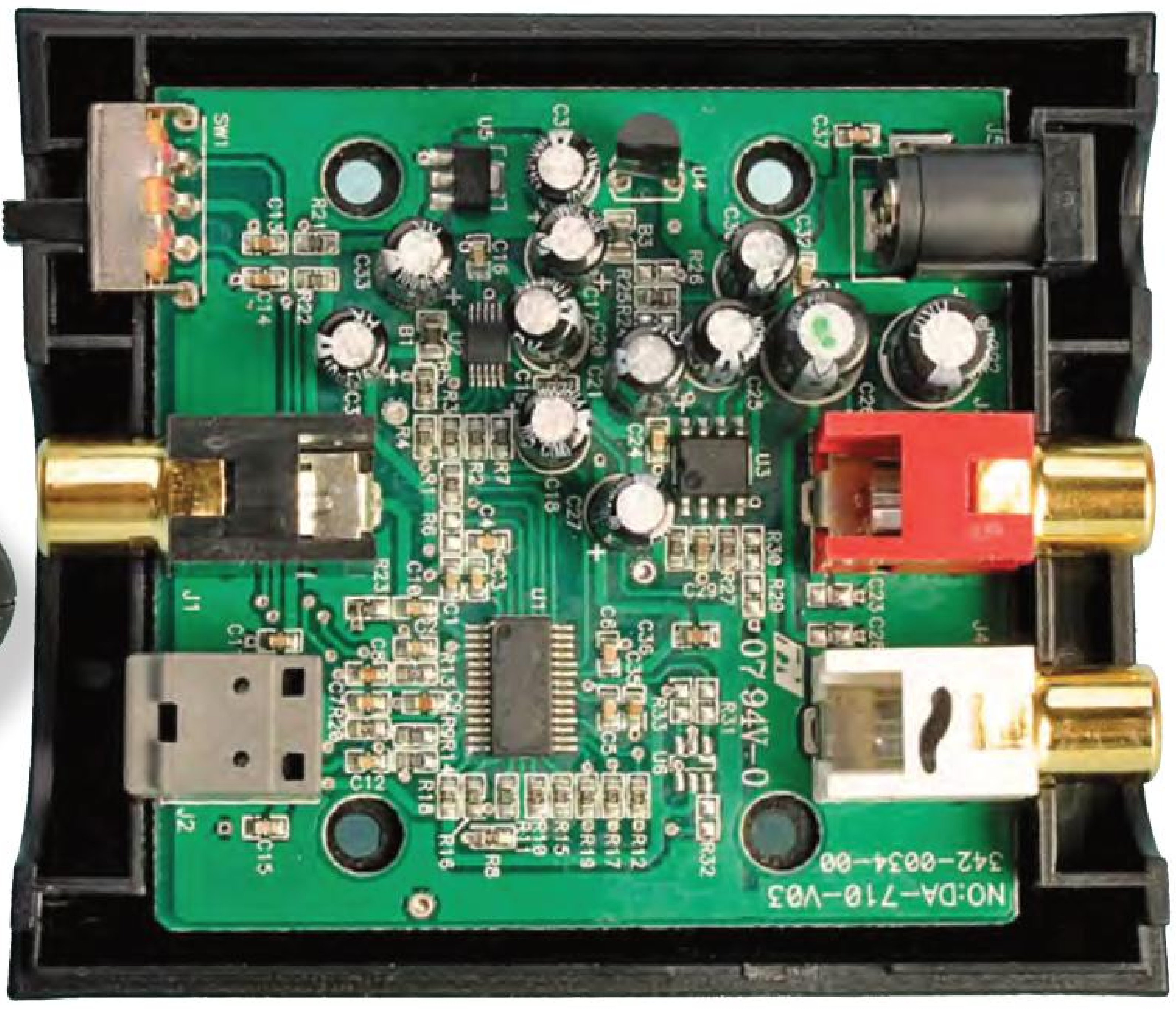

Here's the integrated DAC we used, outside and inside

The main difference is that the two output transistors are driven directly from the voltage amplification stage (VAS), with no driver transistors in between. This design decision is due to the original application of the amplifier being for headphones, where the current requirements are quite small and thus the Class-A VAS is easily able to supply it.

This is still a feasible configuration for a 10W-per-channel amplifier, but we have had to increase the VAS standing current to around 30mA, by using 22Ω resistors at the bases of transistors Q7 and Q19.

Happily, the TIP31 and TIP32 output transistors have quite a good beta figure, which drops as the collector current increases. For 10W output we need a peak output current of 1.65A and the transistors' beta at this sort of current is around 55. 1.65A ÷ 55 = 30mA, hence our choice of the 22Ω resistors. It's only just enough current, but we don't want to use too much of the available power up in the driver stage.

The TIP31 (NPN) and TIP32 (PNP) transistors are readily available and rated at 3A and 40W each; sufficient for our needs in this circuit.

How it works

Let's start with the preamp stages and since both channels are identical, we will just describe the left channel. Any RF signals or ultrasonic noise picked up by the input leads are attenuated by a low-pass filter consisting of a ferrite bead, a 680Ω resistor and a 4.7nF capacitor. The ferrite bead acts like an inductor to block RF. The signal is then coupled via a 470nF capacitor to pin 3 of op amp IC1a, which is configured as a voltage follower. This provides a low source impedance to the preamp gain stages comprising IC2a and IC2b.

IC1a's output is fed to the following stage via a 220µF electrolytic capacitor. This large value ensures good bass response and avoids any distortion that may arise from the typical non-linearity of an electrolytic capacitor with a significant AC voltage across it.

The signal passes to the non-inverting input of IC2a (pin 3) via volume control potentiometer VR1 and a 22µF electrolytic capacitor. This capacitor ensures there is no DC flowing through VR1, which would otherwise cause a crackling noise when it is rotated.

IC2a buffers the voltage at the wiper of VR1 to provide a low impedance for inverting amplifier IC2b. IC2b has a fixed gain of 7, set by the 4.7kΩ and 680Ω resistors. The 100pF feedback capacitor is there to improve circuit stability and reduce high-frequency noise.

Volume potentiometer VR1 is part of the feedback network from the output from IC2b to the input at the 220µF capacitor (from pin 1 of IC1a). Hence IC2a and IC2b form a feedback pair with the overall gain adjustable by VR1.

When VR1 is rotated fully anticlockwise, IC2b's output is connected directly to VR1b's wiper. Thus IC2b is able to fully cancel the input signal (as there is zero impedance from its output to the wiper) and the result is silence (no output signal) from the preamplifier.

Conversely, when VR1 is fully clockwise, VR1b's wiper is connected directly to the input signal, which is then amplified by the maximum amount (7 times) by IC2b. At intermediate settings, the signal at the wiper is partially cancelled by the mixing of the non-inverted (input) and inverted (output) signals and the resulting gain is intermediate.

The way in which this cancellation progresses as VR1 is varied provides a quasi-logarithmic gain curve.

IC1 needs input protection

Because the amplifier may be turned off when input signals are present, IC1's input transistors can be subjected to relatively high voltages; up to 2.5V RMS or maybe 7V peak-to-peak. This will not damage IC1 immediately, but over years, it could degrade performance.

This is because normally very little current flows through the op amp inputs and so the metal traces within the IC are thin. If enough current passes through the inputs (5mA or more), 'metal migration' can cause degradation and ultimately failure.

For that reason, we have included small-signal Schottky diodes D15 and D16 to protect pin 3 of IC1a (and D17 and D18 for pin 5 of IC1b) when the unit is switched off but a large signal is applied.

They clamp the voltage at that input to within ±0.3V of the supply rails under normal conditions, preventing current flow through the op amp input transistors should their junctions be reverse-biased.

So, if the unit is off and the supply rails are zero, the input voltages will be similarly limited to ±0.3V.

The BAT42 diodes have been carefully selected to clamp the op amp input voltages appropriately without having so much leakage current that they will introduce distortion into the signal (Schottky diodes normally have a much higher reverse leakage current than standard silicon diodes). For more information on protecting op amp inputs, see Analog Devices tutorial MT-036, *Op Amp Output Phase-Reversal and Input Over-Voltage Protection*.

We also tested BAT85 diodes. These have slightly higher capacitance when reverse-biased (10pF compared to 7pF) and a significantly higher reverse leakage current (400nA at –15V/25°C compared to 75nA).

However, testing shows no measurable increase in distortion with these

Parts List – Tiny Tim 10W Stereo Amplifier

1 integrated DAC (Jaycar AC-1631)
1 Mini-Reg kit or PCB and parts (*EPE* September 2013)
1 PCB, code 01309111, 198 × 98mm
1 vented metal case, 250 × 220 × 45mm or larger#
1 PCB-mount 6.35mm switched stereo jack socket (3PDT) CON4
6 PCB-mount 6021-type flag heatsinks (Element14 Order Code 1624531)
1 2.5mm DC power plug
6 M3 × 10mm screws and nuts
8 TO-220 insulating washers
6 TO-220 insulating bushes
6 PCB pins
8 M3 × 9mm tapped nylon spacers
16 M3 × 6mm machine screws
1 35 × 15mm section of tin plated steel (eg, cut from a tin can)
3 8-pin DIL sockets (optional)
2 small ferrite beads
4 insulated binding posts: 2 red, 2 black
2 RCA plugs
2 plastic former bobbins
1 2m length 0.8mm diameter enamelled copper wire
1 25mm length 25mm diameter heatshrink tubing
1 1m length light duty figure-8 cable
1 500mm length 2-core shielded cable
1 250mm length 4-core shielded cable
1 1m length red medium-duty hook-up wire
1 1m length black medium-duty hook-up wire
1 250mm length blue medium-duty hook-up wire

Semiconductors
3 LM833 dual low noise op amps (IC1-IC3)
1 7812 positive 12V linear regulator (REG1)
1 7912 negative 12V linear regulator (REG2)
2 TIP31 3A NPN transistors (Q11, Q23)
2 TIP32 3A PNP transistors (Q12, Q24)
4 BD139 1.5A NPN transistors (Q9, Q10, Q21, Q22)
2 BD140 1.5A PNP transistors (Q7, Q19)
2 BC328 PNP transistors (Q25, Q26)
6 BC549 NPN transistors (Q3-Q4, Q8, Q15-Q16, Q20)
8 BC559 PNP transistors (Q1-Q2, Q5-Q7, Q13-Q14, Q17-Q19)
1 5mm LED (LED1)
12 1N4004 1A diodes (D3-14)
4 BAT42 Schottky diodes (D15-D18)
(or use BAT85#)

Capacitors
2 4700µF 25V electrolytic
2 220µF 50V electrolytic*
7 220µF 25V electrolytic*
2 100µF 50V electrolytic*
4 47µF 16V electrolytic*
2 22µF 16V electrolytic*
2 470nF MKT
2 150nF MKT
7 100nF MKT
2 4.7nF MKT
2 680pF C0G/NP0 ceramic
2 220pF C0G/NP0 ceramic
2 100pF C0G/NP0 ceramic

* Low ESR 105° types preferred if their diameter is no more than 6.3mm for 22µF/47µF and 8mm for 100µF/220µF.

See text

Resistors (0.25W, 1%)
4 100kΩ 1 30kΩ 3 22kΩ 6 10kΩ 2 4.7kΩ 2 3.3kΩ
10 2.2kΩ 4 1.8kΩ 2 1.2kΩ 1 1kΩ 4 680Ω 2 220Ω
4 100Ω 4 68Ω 2 47Ω 6 22Ω 6 10Ω
8 1.2Ω(0.5W, 5%)
1 10kΩ dual gang linear 16mm potentiometer. with knob (VR1)
2 500Ω sealed horizontal trimpots (VR2, VR3)

Power supply board

1 PCB, coded 18110131, 75 × 100mm
1 30VA 15+15VAC toroidal transformer
or
1 20VA 15+15VAC toroidal transformer
1 M205 fuse holder with clip-on cover
1 1A slow-blow M205 fuse
2 3-pin headers, 3.96mm pitch, with centre pin removed #
1 250VAC switch with double-sheathed lead and sheathed terminals, terminated with 3-pin, 3.96mm pitch header plug #
1 twin core mains lead, double-sheathed and terminated with 3-pin, 3.96mm pitch header plug #
1 3-way terminal block
4 M3 × 9mm tapped nylon spacers
8 M3 × 6mm machine screws
1 W04M 1.5A bridge rectifier (BR1)
2 4700µF 25V electrolytic capacitors
2 10kΩ 0.25W 5% resistors

in place of the BAT42s, so they are an acceptable substitute.

Amplifier circuit

Low-noise PNP transistors Q1 and Q2 are the differential input pair, with the base of Q1 being the non-inverting input to the amplifier and the base of Q2 being the inverting input. Q1's base is tied to ground by a 1.2kΩ resistor (to match the 1.16kΩ source impedance at the base of Q2) and is bypassed by a 100nF capacitor to reduce high-frequency noise.

The signal from the preamplifier is fed to the base of Q2 via a 3.3kΩ feedback resistor, so that the amplifier works in the inverting mode. This gives the amplifier stages a gain of:

–3.3kΩ ÷ 1.8kΩ = –1.83.

PNP transistor Q5 operates as a 3mA constant-current source (0.65V ÷ 220) to feed the Q1/Q2 input pair. Negative feedback for current regulation is provided by another PNP transistor, ie, Q6. It has a bootstrapped collector current sink (two 10kΩ resistors and a 47µF capacitor), so that it operates consistently.

NPN transistors Q3 and Q4 form a current mirror for the input pair, with 68Ω emitter resistors to improve its accuracy. Any difference in the current through Q1 and Q2 must then flow to the base of NPN transistor Q8. So Q1-Q5 form the transconductance stage of the amplifier.

Together, Q8 and Q9 form a Darlington transistor, configured as a common-emitter amplifier. PNP transistor Q7 acts as a constant-current source for its collector load, sourcing about 30mA (0.65V ÷ 22Ω). Q6 provides current regulation feedback for Q7 as well as Q5.

The 680pF and 220pF capacitors between Q9's collector and Q8's base, together with the 2.2kΩ resistor from their junction to the negative rail, form the 2-pole frequency compensation scheme mentioned earlier. Together, transistors Q7-Q9 are the voltage amplification stage.

Because Q7 and Q9 have to handle significantly more voltage and current in this beefed-up version of the amplifier (compared to the original headphone amplifier circuit), their dissipation has increased beyond the capabilities of the small TO-92 signal transistor package. We calculate their dissipation as around 20V × 30mA = 600mW while the limit of a TO-92 package at 55°C is about 500mW.

As a result, we have had to change them to BD139 and BD140, which are 80W transistors rated at 80V and 1.5A. These are in TO-126 packages which can dissipate just under 1W at 55°C with no heatsink. But they have a different pin-out to those originally specified (ie, BC337/338 and BC549) so it will be necessary to bend their leads when they are installed on the PCB. You can see how we did this in the photo of the PCB.

V_{BE} multiplier

Between Q7 and Q9 is Q10 (another BD139) which functions as a V_{BE} multiplier to set the quiescent current for the output transistors Q11 and Q12. Q10 is mounted on the back of Q11's heatsink so that its junction temperature tracks the output stage. Thus, its V_{BE} tracks that of the output transistors (Q11 and Q12), so the bias voltage varies to compensate for changing output transistor temperature, keeping the standing current through them more or less constant.

VR2 is used to adjust this current, while the 2.2kΩ resistor prevents the bias from becoming excessive if VR2's wiper goes open-circuit, as it may do while it is being trimmed. A 47µF capacitor filters the bias voltage, improving distortion performance when the output voltage swing is large.

The resulting bias voltage is applied between the bases of output transistors Q11 (NPN) and Q12 (PNP) via 22Ω stopper resistors, which prevent parasitic oscillation. Each output transistor has a 0.6Ω emitter resistor (two 1.2Ω resistors in parallel) which helps to linearise the output stage and stabilise the quiescent current.

Current limiting

While it's always a good idea to plug and unplug the headphones while the power switch is off, we can't rely on that and we don't want the output transistors to blow when it happens. Therefore, both Q11 and Q12 are protected against over-current conditions.

Q11 is current-limited because the 30mA current source (Q7) sets a maximum limit for its base current. According to the TIP31 data sheet, at 25-125°C, the maximum collector current will be about 1.65A, well within its safe operating area (SOA) as long as the short-circuit is brief.

Q12 is more of a concern because Q9 can sink significantly more than 30mA. The 10kΩ resistor at Q8's collector ultimately limits how much current Q9 can sink as follows. Q8's maximum collector current is around (12V – 0.7V) ÷ (10kΩ + 2.2kΩ) = ~1mA. According to the BC338 data sheet, Q9's maximum current gain figure is around 160, so the maximum it can sink is about 160mA.

However, if this much current were pulled from Q12's base then it would fully saturate (turn on hard), exceeding its SOA and possibly causing it to fail. Q25 and D7 prevents this. Should the current flow through Q12's collector-emitter junction exceed 2A (within its SOA), the drop across the 0.6Ω emitter resistor exceeds 2A × 0.6 = 1.2V.

At this point, Q25's base-emitter voltage increases beyond 1.2V – 0.6V = 0.6V and so Q25 starts to turn on, shunting current around Q12's base-emitter junction and preventing Q12 from turning on harder. Any current sunk by Q9 beyond that necessary for Q12 to pass 2A goes through D7 and Q25 rather than Q12's base-emitter junction.

Output RLC filter

The output filter isolates the amplifier from its load at high frequencies, improving stability. Because this amplifier circuit is already fairly stable (thanks to its simple output stage), we can get away with slightly less inductance than usual (4.7µH rather than 6.8µH or 10µH). We can thus use a thinner gauge wire which is slightly easier to wind, for roughly the same DC resistance.

Ideally, the output filter should be optimised for the expected load impedance, but because headphones have such a wide range of impedances, all we can do is compromise and specify an intermediate value. As a result, for higher impedance headphones, the amplifier has a slightly elevated response at above 20kHz.

For 4Ω and 8Ω loudspeaker operation, the high frequency response is virtually flat and then for higher load impedances, up to infinity, the gain increases to as much as +0.13dB at 20kHz. The increase is slightly lower (+0.09dB) for the most common headphone impedances of 16Ω and 32Ω. This deviation is so small as to be imperceptible.

In fact, all our amplifier designs using this type of output RLC filter (devised by the late audio genius Neville Thiele) have such a response with higher than usual output impedances or no load.

Power supply

We have had to increase the voltage and current of the power supply in order to allow the modified amplifiers to deliver the target of 10W per channel. Instead of a 12VAC 2A plugpack (ie, 24VA) we are using a 20VA or 30VA 15-0-15 toroidal transformer (T1). We have also modified the PCB so that the amplifier sections run from the unregulated ±20V supply rather than the regulated ±12V supply, which was sufficient for driving headphones, but a bit limiting for loudspeakers.

Another benefit of using the toroidal transformer is that it has a centre tap which means we can use a bridge rectifier (BR1) to get full-wave rectification, recharging the filter capacitors at 100Hz rather than 50Hz. This reduces supply ripple and thus reduces residual hum while increasing available power and dynamic headroom.

T1 and BR1 are mounted on a small secondary PCB that forms a self-contained mains power supply. We have done this for a number of reasons; one is that it allows us to build the unit as a double-insulated piece of equipment.

Most commercial devices that constructors are likely to 'rat' for their amplifier housing will already be double-insulated (and thus have no earth connection).

We pulled the pin headers off the power supply PCB of the recycled set-top box and re-used these on our board, allowing the pre-existing mains cable and mains power switch to simply plug in, as they did before.

While we were at it, we stuck another pair of 4700µF filter capacitors on the power supply board. This improves the power supply filtering and also means that very little 100Hz current passes through the wiring between the two boards, minimising hum coupling into the amplifiers.

Switch-on/off behaviour

You may notice that there is no speaker protector or de-thump circuit. Neither is really necessary in this case. The amplifier's power supply can only deliver about 40W and this is unlikely to do much damage to a speaker in the case of a circuit failure, especially since some of this would be dissipated in the amplifier itself.

As for switch-on and switch-off thumps, the headphone amplifier circuit was already designed to minimise these and since speakers are significantly less sensitive, these should be kept well under control.

This was partly achieved by removing the capacitor which would typically be between Q5's base and the positive rail (as present in the *20W Class-A Amplifier*). Despite changing the circuit to run from an unregulated supply, virtually no ripple seems to make its way to the amplifier outputs, as demonstrated by the very good signal-to-noise ratio of –120dB (including the preamplifier!).

Diodes D11 and D12 (D13 and D14 in the right channel) are important for proper switch-on behaviour. While the ±12V regulated rails are already protected to prevent the positive rail from going negative and vice versa, the RC filtered supply rails for the early amplifier stages can still suffer from this problem unless extra steps are taken. That's because the filter resistors isolate the capacitors from the clamp diodes D4 and D6.

Without D11 and D12, the positive filtered rail could be briefly pulled negative and this would cause an amplifier output excursion. This could cause unwanted noises in the speakers at start-up.

The different positive and negative rail filter resistors (10Ω and 47Ω respectively) allow the positive rail to come up more quickly, which also helps achieve a clean switch-on. Together, these details allow the amplifiers to operate normally just milliseconds after both filter capacitors are partially charged.

Similarly, diodes D9 and D10 clamp the RC-filtered supply for the op amps in the preamplifier. Without these, the op amp input transistors may become briefly reverse-biased at switch on, causing supply current to flow into the AC-coupling capacitors and again causing a thump to be generated.

Finally, the 1k resistor in parallel with D10 discharges the op amp negative supply rail faster than the positive rail when power is removed. The op amps are prone to oscillation when their supply capacitor is mostly discharged and this can cause a 'chirp' at switch-off. With the 1kΩ discharge resistor, this chirp is made very short and often eliminated entirely.

Part 2

In February's *EPE* we will present the construction details and describe the setting-up procedure. That includes details of the new power supply board and mounting both PCBs, plus the small off-the-shelf DAC, inside the case.

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Something old, something new...

Mark Nelson

...nothing borrowed, but something blue! The month, Mark Nelson puts LEDs under the microscope in the sincere hope of convincing you that these devices are far more fascinating than you might imagine. Read on to take the challenge!

BLUE IS THE CORPORATE COLOUR of the mobile phone/cellular radio operator O2, and every year at Christmas time it decks out its customer stores with decorations made of blue LEDs, which I find utterly enchanting. But the appeal of blue LEDS doesn't stop there – as demonstrated by the Nobel Prize committee – who have just awarded the 2014 physics prize jointly to three researchers: Isamu Akasaki, Hiroshi Amano and Shuji Nakamura 'for the invention of efficient blue light-emitting diodes, which has enabled bright and energy-saving white light sources'. Anything energy-saving floats my boat – but what about life-saving as well?

True blue life saver

Among the often forgotten or ignored diseases, type 2 diabetes is still a silent killer. Around half the sufferers diagnosed for the first time each year are unaware they might have the condition. In Britain alone it is estimated that there are up to 630,000 people who have the condition but are ignorant of their status because they simply do not recognise early symptoms. Left untreated, the disease can lead to serious long-term complications: for example, heart disease, stroke, kidney failure and damage to the eyes.

Researchers in Germany at the Ludwig-Maximilians University (LMU) have discovered that blue LED light can help diabetics regulate blood glucose. They have chemically modified an anti-diabetic agent to make its action dependent on light. The resulting prototype compound, termed JB253, induces the release of insulin only when pancreatic cells are exposed to blue light. LMU professor, Dirk Trauner explains the principle as follows: 'We utilise synthetic molecular switches whose structure is altered by light in conjunction with the natural receptor proteins for specific signalling molecules. The chemical switches effectively make the receptors' function dependent on exposure to light of a certain colour. Light can be controlled with exquisite precision, which allows us to target the receptor of interest with very high specificity. In addition, the activating reaction is itself reversible.'

Dr Hodson of Imperial College London, who has collaborated in this research, explains the practical benefits of these light-sensitive drugs. 'They could be administered in the form of a pill, and then be released or activated by irradiating a patch of skin with a blue LED. When the light is switched off the drug flips back into the inactive form. We have a long way to go before it will be possible to use such a therapy in patients. It would, however, give better control over blood sugar levels during type 2 diabetes, and would reduce the incidence of side-effects, because the active agent is released only where it is required,' he concludes.

I make no apology for stressing this point, even though I know you read this magazine to read about practical electronics, not medical matters. If you suffer an unquenchable thirst, frequent toilet trips, occasional blurred vision and wobbles or permanent tiredness, do see a doctor; these are the classic signs of type 2 diabetes. It's not curable, but it is treatable, and 90 per cent of sufferers can control it by being careful with their diet, taking tablets or a combination of both. Ignoring the symptoms will have very unpleasant consequences – now back to electronics!

Who wants superfast fibre broadband?

We all do – so what's holding it up? Physical constraints are one of the factors, because the slow speed at which LEDs can be turned on and off has throttled back their use as a light source in light-based telecommunications. But now, new research at Duke University, a private research university located in North Carolina in the US, may help clear away the road block using ultra-fast LEDs.

'We have made fluorescent molecules emit photons of light 1,000-times faster than normal, setting a speed record and making an important step toward realising superfast light-emitting diodes (LEDs),' claims Maiken Mikkelsen, an assistant professor at the university 'One of the applications we are targeting with this research is ultra-fast LEDs,' he points out.

Using a kind of 'doping' process, where fluorescent molecules are placed near intensified light, the molecules emit photons at a faster rate through an effect called Purcell enhancement. Gleb Akselrod from Mikkelsen's laboratory explains that the researchers found they could achieve significant speed improvement by placing fluorescent molecules in a gap between 'nanocubes' and a thin film of gold. 'When we have the cube size and gap perfectly calibrated to the molecule, that's when we see the record 1,000-fold increase in fluorescence speed,' he explained.

Finally, something old

LEDs are of course solid-state light-emitting devices, but did you know they actually pre-date transistors? A British discovery, they date back in fact to the year 1907, when the Marconi company engineer Henry Round published a short letter in *Electrical World* magazine. 'During an investigation of the unsymmetrical passage of current through a contact of carborundum and other substances a curious phenomenon was noted. On applying a potential of 10 volts between two points on a crystal of carborundum, the crystal gave out a yellowish light,' he wrote.

To him it was no more than a curiosity and twenty years later the Russian scientist Oleg Losev was the first to investigate the effect, propose a theory of how it worked, and consider practical applications for his 'luminous carborundum detector'. Miniature non-vacuum light sources that operated at low voltages (less than 10V) and at very high speed could perform tasks that normal light bulbs could not and his 1927 patent for a 'light relay' foresaw its use 'for fast telegraphic and telephone communication, transmission of images and other applications when a light luminescence contact point is used as the light source connected directly to a circuit of modulated current' – in other words, the optoelectronic systems that make modern communications possible. Tragically, his promising investigations ended in 1942 when he died of starvation in the Siege of Leningrad, aged only 39.

EPE EXCLUSIVE

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A solderless prototyping block is included for quick exploration of the application examples described in the 'hands-on' labs included in the user's guide. These labs provide an intuitive introduction to using common peripherals and include useful application examples, from lighting an LED to some basic mixed-signal applications using the free HI-TECH C PRO for the PIC10/12/16 MCU Family Lite Mode Compiler.

Alternately, a companion guide featuring the free version of Matrix Multimedia's Flowcode V3 Visual Programming Environment (VPE) provides a flowchart-based method of implementing a series of introductory labs. A free version of Flowcode V3 can be downloaded on the Microchip website.

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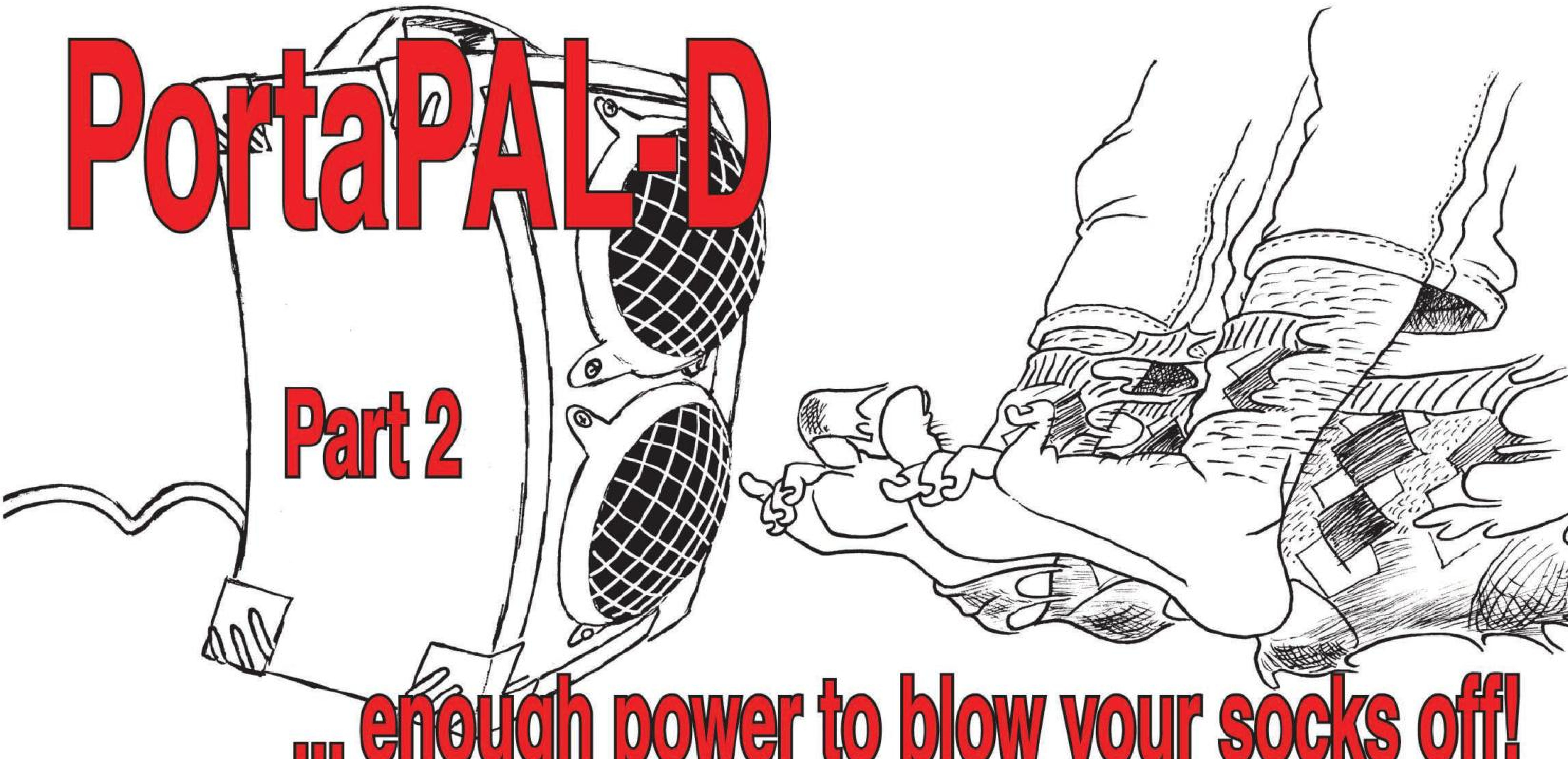
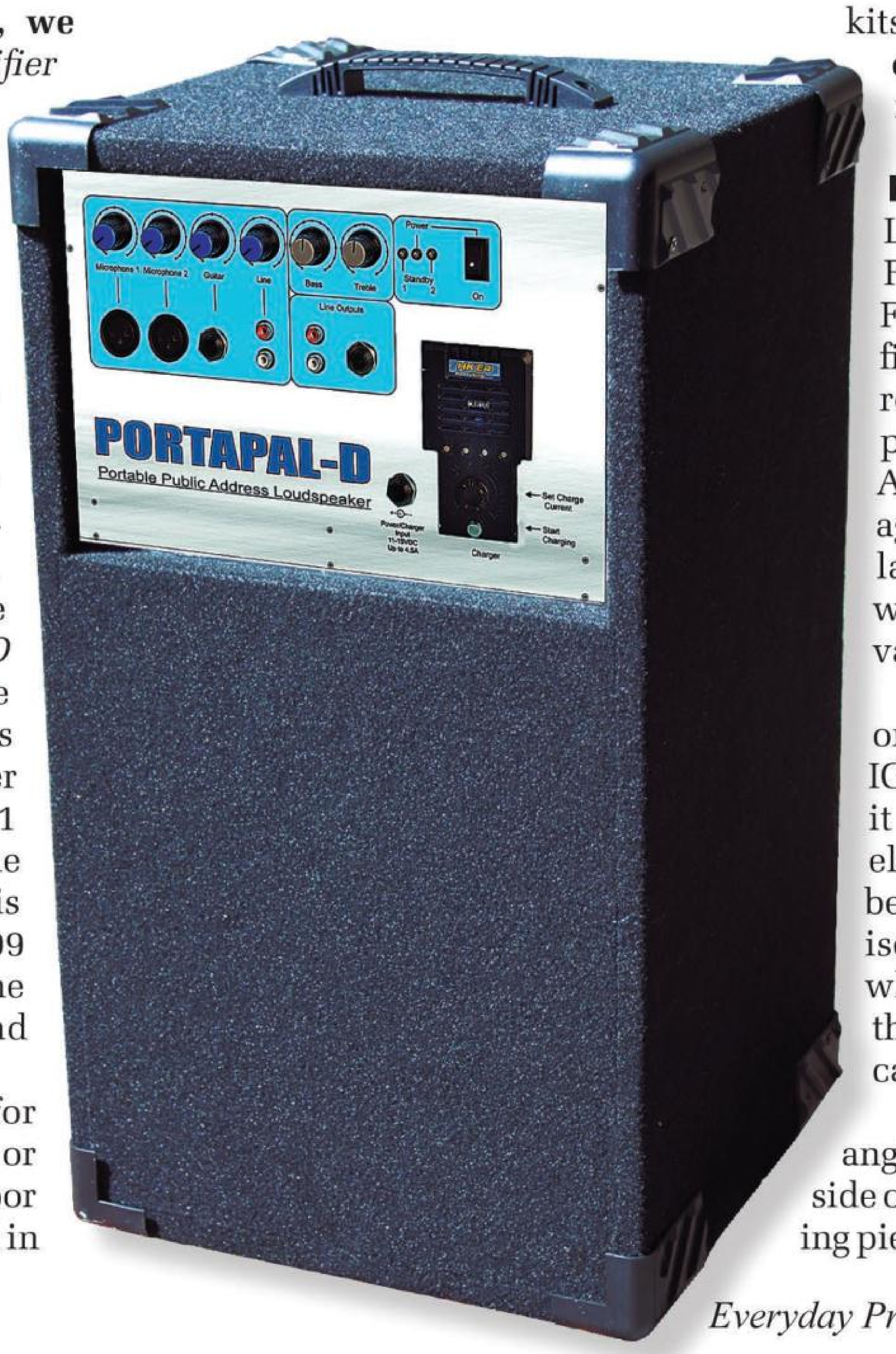
PortaPAL-D

Part 2



... enough power to blow your socks off!

In the second part of our new, go-anywhere Portable PA system, we put together all the electronics. There's a lot to it, but we've separated out each section to simplify matters. So let's get stuck into it!



As described last month, we use the *CLASSiC-D Amplifier* module and its matching speaker protector from the November and December 2013 issues, along with the *DC-DC Converter* from May 2014, which allows the *CLASSiC-D Amplifier* to run from a 12V supply.

Both the *CLASSiC-D Amplifier* and the speaker protector need to be set up for the ±35V supply option, as detailed in their construction – but more on this later.

First, we will describe the building of the main *PortaPAL-D* mixer and input PCBs. There are three PCBs for these: the largest is the main PCB (mixer and power supervision) coded 01111131 and measuring 212 × 100mm; the guitar and line input/output PCB is coded 01111132 and measures 109 × 35mm and finally the microphone input PCB coded 01111133 and measuring 64 × 73mm.

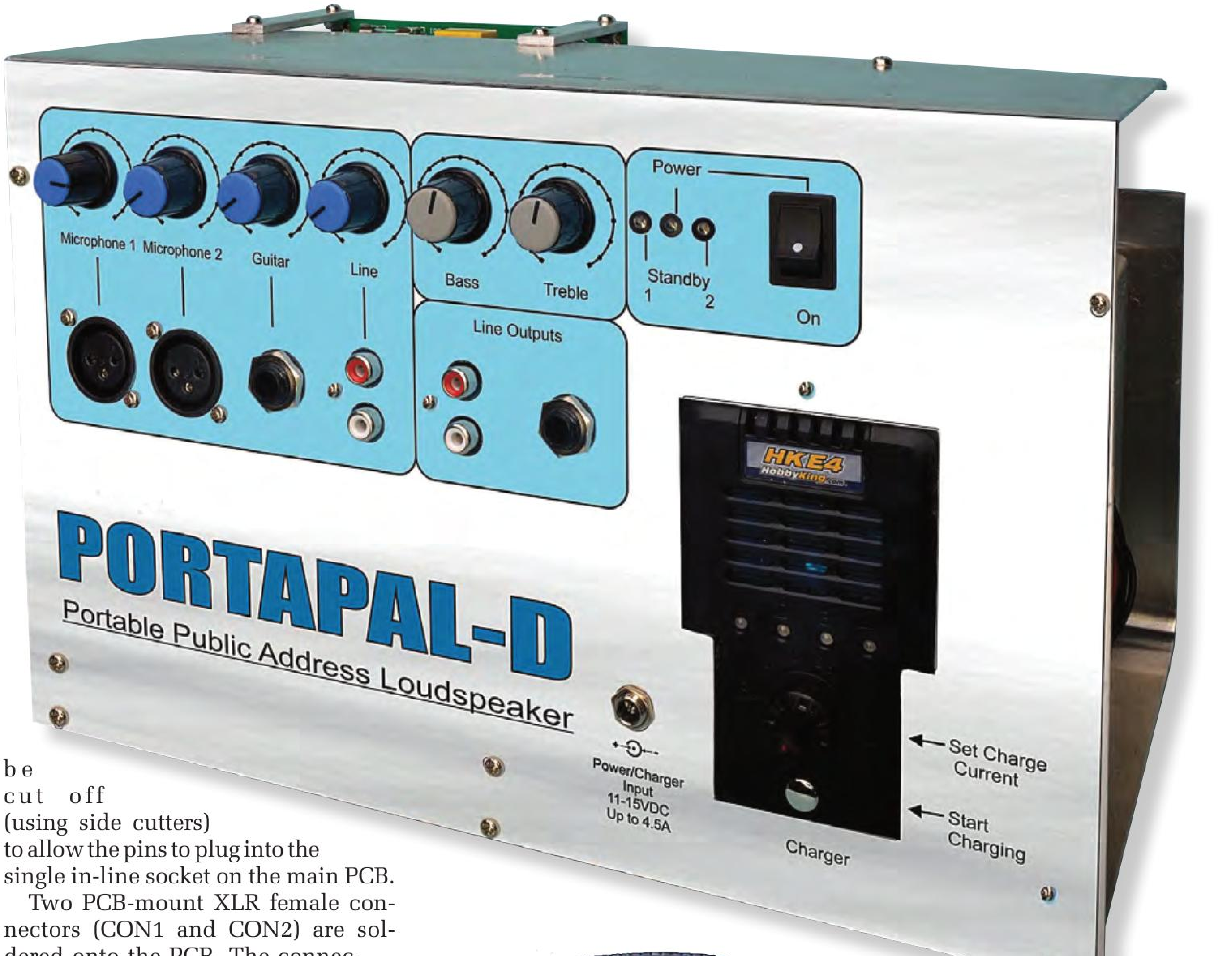
Check each PCB carefully for any problems such as undrilled or incorrectly sized holes, and for poor etching. Typically, PCBs supplied in kits or from the *EPE PCB Service* are excellent quality and should not require any repairs.

Microphone input PCB

Let's start with the smallest PCB. Follow the overlay diagram in Fig.7. The resistors are installed first, but note that the four 1kΩ resistors each have a ferrite bead placed over the lead at one end. As well as checking each resistor against the colour code shown last month, measure each one with a multimeter to verify its value.

IC1 can be directly soldered onto the PCB or mounted using an IC socket. Either way, make sure it is oriented correctly. Similarly, electrolytic capacitors (which can be installed next) are also polarised. For the smaller capacitors, where the value is not printed on them, the codes were shown in the capacitor codes table last month.

CON3 comprises a 6-way right-angle pin header. Along the longer side of the header is a thin plastic backing piece behind the pins. This needs to


Microphone 1
Microphone 2
Guitar
Line
Bass
Treble
Line Outputs
Power
Standby
1
2
On
HKE4
HobbyKing.com
PORTAPAL-D
Portable Public Address Loudspeaker
Power/Charger Input 11-15VDC Up to 4.5A
Charger
Set Charge Current
Start Charging

be cut off (using side cutters) to allow the pins to plug into the single in-line socket on the main PCB.

Two PCB-mount XLR female connectors (CON1 and CON2) are soldered onto the PCB. The connectors are ultimately secured to the front panel with self tapping screws. The central hole at the top of the PCB under the XLR connectors is for a chassis-mount earth point.

This can be a 6.4mm spade terminal or a crimp eyelet that mounts on the rear of the PCB using an M3 screw and nut with star washers top and bottom of the PCB to ensure a good earth connection to the PCB copper.

Guitar and line input and output PCB

Like the first board, construction can begin with all resistors and capacitors. Again, take care with the polarity of the electrolytic capacitors. Like IC1, IC2 can be either directly mounted onto the PCB or with a socket. Be sure to orient the socket and IC correctly.

The 6.35mm jack sockets (CON4 and CON7) as well as the stereo RCA sockets (CON5 and CON6) mount as far down onto the PCB as they can go before soldering the pins.

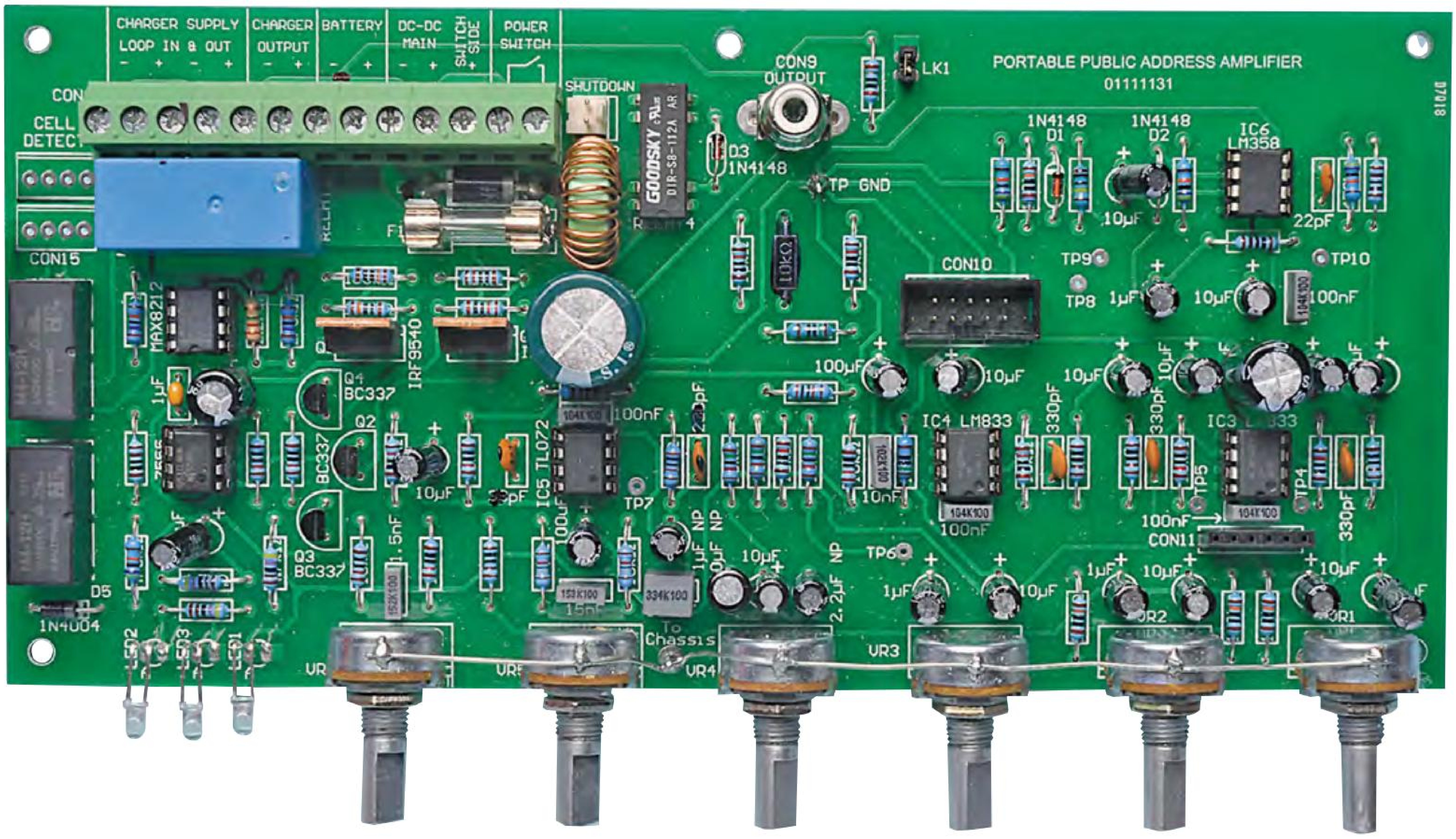
Finally, insert and solder in the 10-way IDC connector with the notched section toward CON6.

Mixer and power supervision PCB

This PCB overlay is shown in Fig.8. Construction follows the same pattern: resistors first, followed by the diodes. There are three types used; 1N4148s, a 1N4004 and a 1N5404. Make sure these are inserted in their correct positions and with the correct orientation.

Two PC stakes are used on the PC board. One is for TP GND and the other for the GND pin between VR4 and VR5. The remaining test points do not use PC stakes – their tinned pads on the PCB can be probed with an oscilloscope probe or meter lead if necessary.

ICs can be installed now – again, sockets are optional but watch polarity and position. Capacitors follow (watch polarity on electrolytic types)



and refer to the capacitor table last month if in doubt.

The two fuse clips each have an end stop to prevent the fuse sliding out. Install each clip with the end stop facing to the outside.

Transistors are installed as shown. These are all BC337 types. LEDs are mounted by bending the leads at right angles at 15mm back from the body of the LED. The LEDs are to face forward with the anode (longer lead) to the left. The two outer LEDs are red, while the middle LED is green.

Inductor L1 is wound on a 28 × 14 × 11mm iron-powder toroid with 24 turns of 1mm enamelled copper wire. After winding, the enamel needs to be scraped off the wire ends so that it can be soldered to the PCB.

The four relays can now be installed, along with the vertical RCA socket (CON9), the 6-way SIL socket (CON1) and the 10-way IDC connector (CON10). The latter needs to be installed with the notch oriented as shown.

The two-pin header CON12 is installed adjacent to L1. Although this header has a polarity key to prevent reverse connection, its orientation is not important. The two-pin header for LK1 can also be installed now.

CON14 and CON15 don't use plugs and sockets – their wires directly solder onto the PCB plugs and sockets. They are for connecting the '3S 250mm 2xJST-XH parallel balance lead'. This lead has a 4-way socket at one end that branches out to two 4-way plugs. The lead is cut to provide just one plug on a 4-way lead and one socket on a 4-way lead. Cut the leads to get the maximum lead length that you can. Then strip back the insulation on each wire by about 4mm and insert into the CON14 and CON15 holes. You can place the plug or socket lead set in either the CON14 or CON15 position.

However, it is important to insert the wires so that there is the same order between the plug lead and socket lead. We had the red lead on each lead set inserted in the outside hole followed by the black leads in the order they terminate to the plug or socket. A cable tie located close to the PCB holds all the wires together.

The 13-way screw terminals are made up using five 2-way terminals and a 3-way terminal. These terminals dovetail together first, before inserting the entire 13 terminal set into the holes on the PCB, with the wire entry toward the outside of the PCB.

Finally, the potentiometers (VR1-VR6) can be installed. Before you do so, however, a little 'surgery' is needed and it's easiest to do it before the pots are soldered in.

As the pot bodies need to be earthed to the GND PC stake (between VR4 and VR5), you will need to scrape a small patch of the passivated coating from each pot body, using a hobby knife, at the position where the wire is to be soldered. This will allow the solder to flow onto the steel surface below the passivated coating.

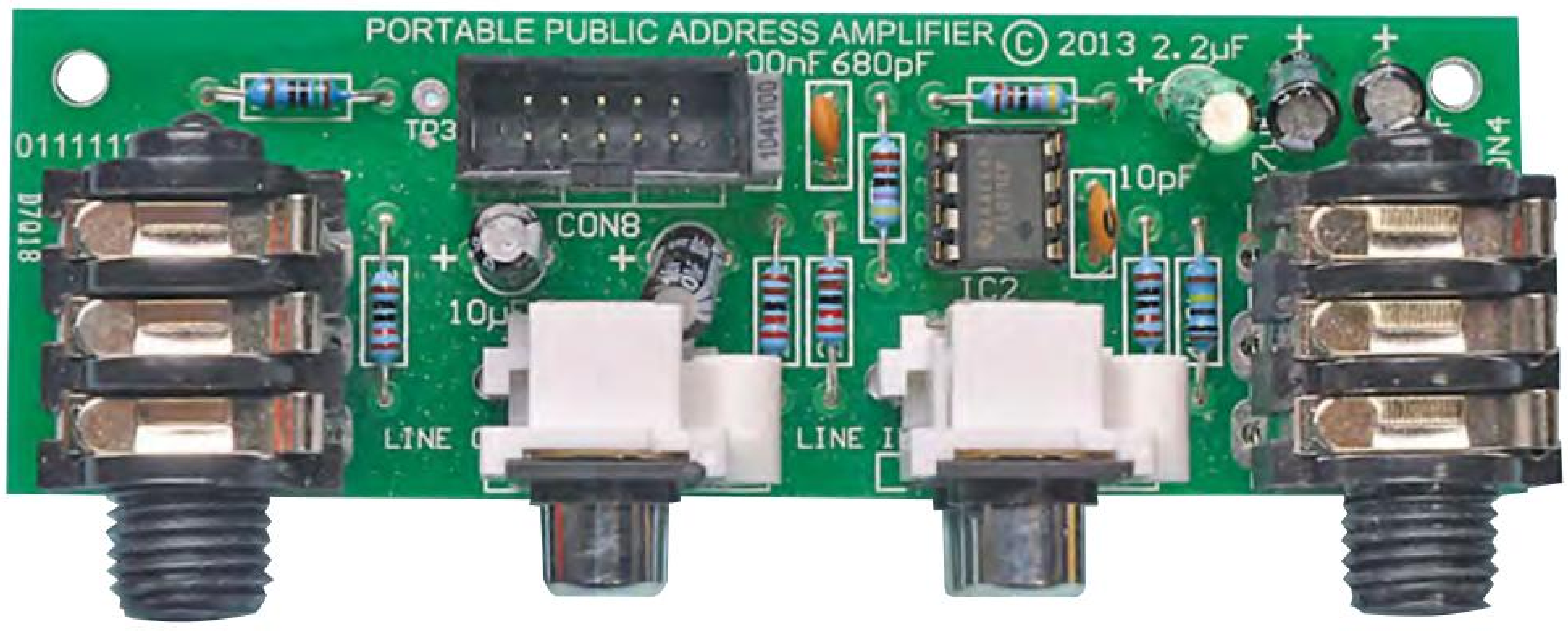
And if the pot shafts are too long, cut each pot shaft to about 12mm long to suit the knob that's used. Clean up the cut edges with a file so that the knob will push on readily. Also, the locating tabs on the pots need to be snapped off using pliers. Now install each pot taking care to place the 10kΩ logarithmic (log) potentiometers in positions VR1-VR4 and the 100kΩ linear potentiometers in positions VR5 and VR6.

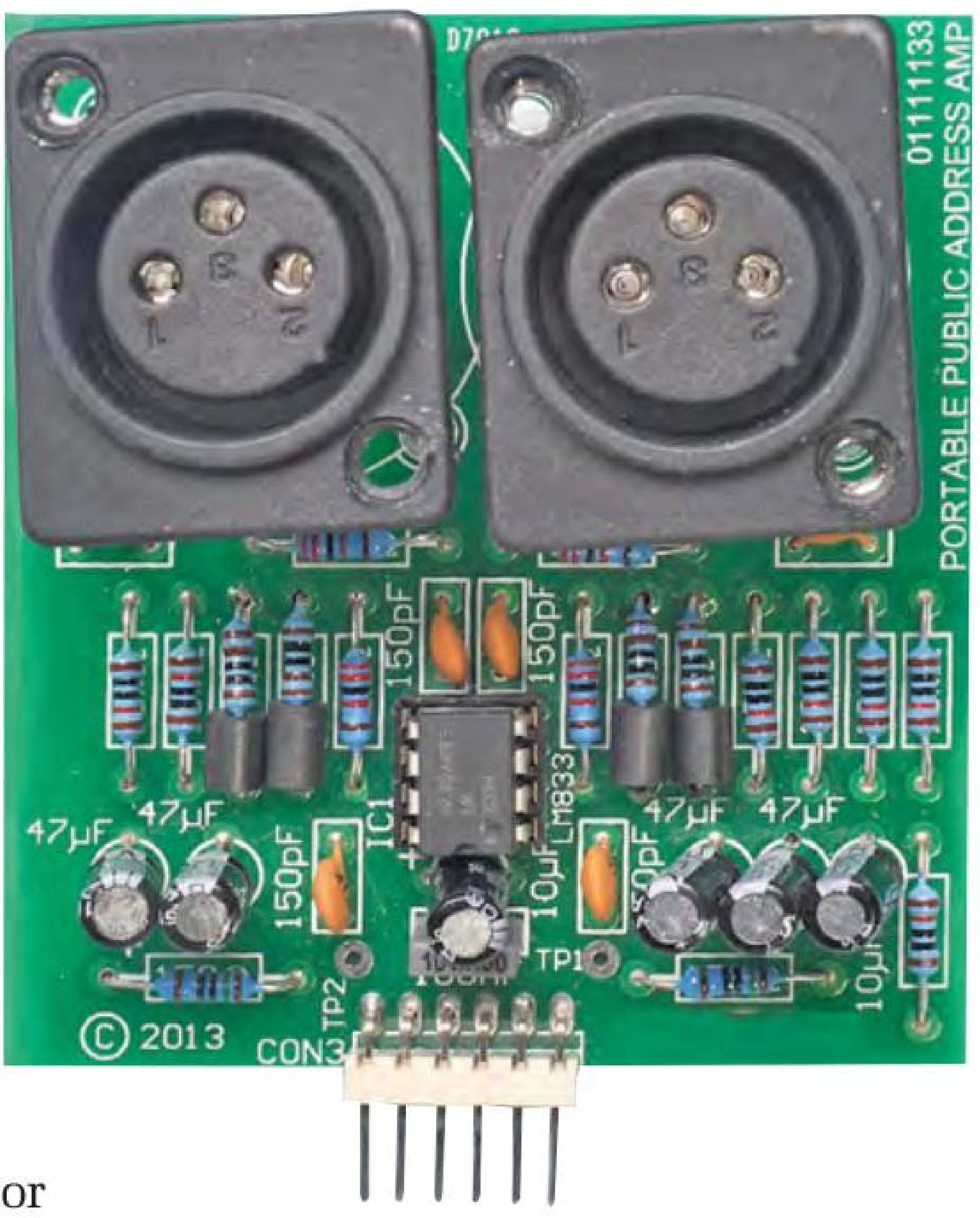
CLASSiC-D Amplifier

The *CLASSiC-D Amplifier* is built according to the articles in November and December 2013. There are some differences in building this for use with the *PortaPAL-D*.

First, use the 'Component Values vs Supply Voltages' table on page 30 of the December 2013 issue to set up the amplifier for ±35V. Additionally, do not install the horizontal RCA socket (the one that protrudes past the edge of the PCB) – just install the vertical-mount RCA socket.

Heatsink drilling is also changed to include the 50°C thermostat that is secured to the right-hand side of the heatsink (above the V_{CC} and COM PC stakes). The thermostat is attached


PORTABLE PUBLIC ADDRESS AMPLIFIER © 2013 2.2µF
100nF 680pF
TP3
CON8
10pF
IC2
LINE O
LINE I
CON4


01111133
PORTABLE PUBLIC ADDRESS AMP
150pF
IC1
LM833
47µF
10µF
TP2
TP1
© 2013
CON3

At left is the main PCB (mixer and power supervision) shown slightly less than full size. Note the wire soldered to all pot bodies and then to the PCB. Above is the guitar and line input PCB (left), shown full size, and similarly the microphone input PCB at right. The XLR (microphone) sockets on this board look slightly skewiff... because they are! We didn't have any PCB mounting sockets on hand and the photographer was waiting! Your board, using the right sockets, should look perfect.

using M3 screws that are screwed into M3 tapped holes in the heatsink. The thermostat is mounted as high on the heatsink as possible without the thermostat body showing above the heatsink edge. The screw holes are positioned to pass though the heatsink and between the fins.

The ground lift jumper shunt is installed for the *PortaPAL-D*. This ensures the minimum noise is produced.

Speaker protector

The *CLASSiC-D Amplifier's Speaker Protector* should be constructed as shown in Fig.23 of the December 2013 issue, using the values shown for use with a 35V supply. The 47µF delay capacitor is changed in value to 10µF. As the only capacitor on the PCB, it is easy to locate. The capacitance change improves the overall response of the *PortaPAL-D* when switching from standby to producing an output.

DC-DC Converter

Build the *DC-DC Converter* as it is shown in the May 2014 issue except for two alterations. First, change the 13kΩ resistor connecting to the anode of D3 to 10kΩ. On the PCB, this is located between ZD1 and diode D3. This resistance change reduces the low battery shutdown voltage of the *DC-DC Converter* to 10V. This is more suited to the LiPO battery used in the *PortaPAL-D*. The second change is not to connect the earth wire from the TP GND terminal to the chassis. Instead, the *DC-DC Converter* case is earthed directly to the *PortaPAL-D* chassis once it is secured in place.

Chassis

As shown in our photos, the *PortaPAL-D* is built on two L-shaped aluminium chassis panels which screw together into an open-ended box. Each of these panels is bent from a 300 × 300mm × 1mm aluminium sheet.

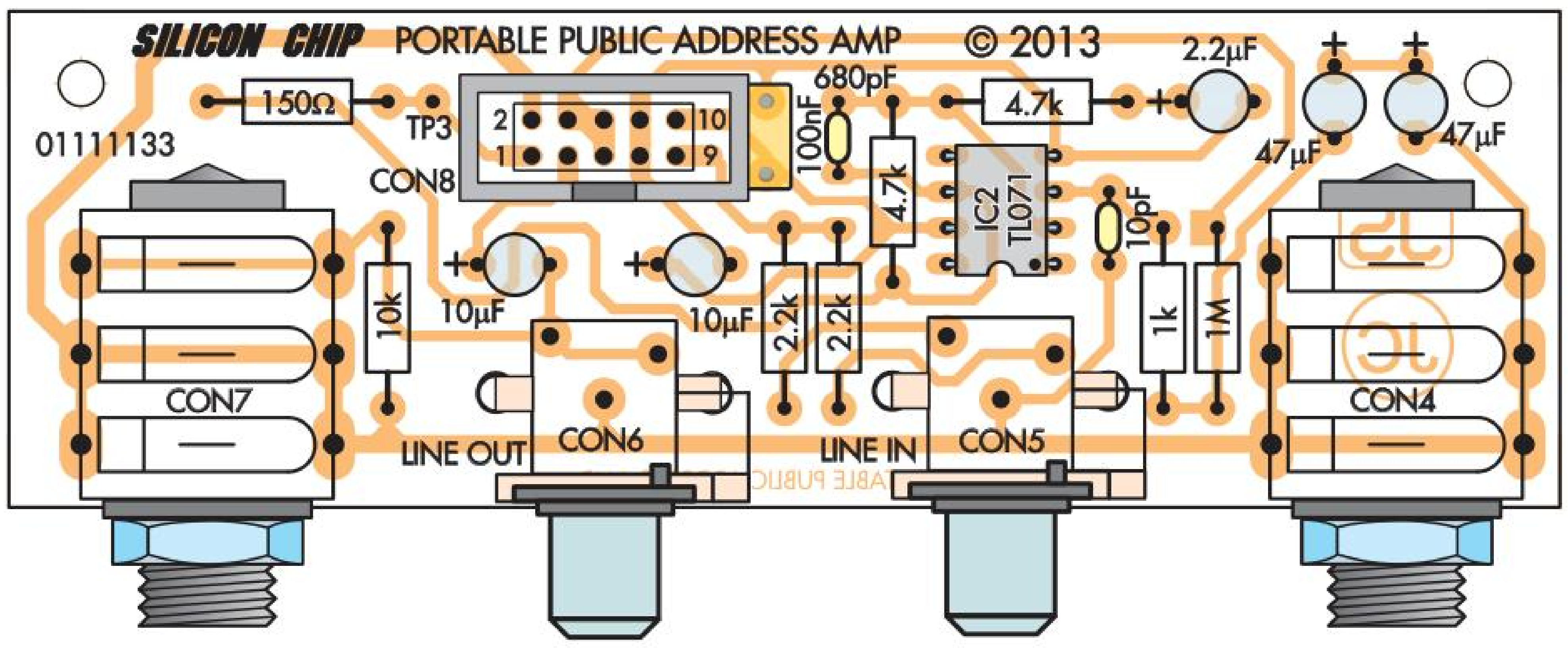
Fig.10 and 11 show the folding and drill layout for these two panels which can be made using basic hand tools. Some of the holes are countersunk, as shown in Fig.11.

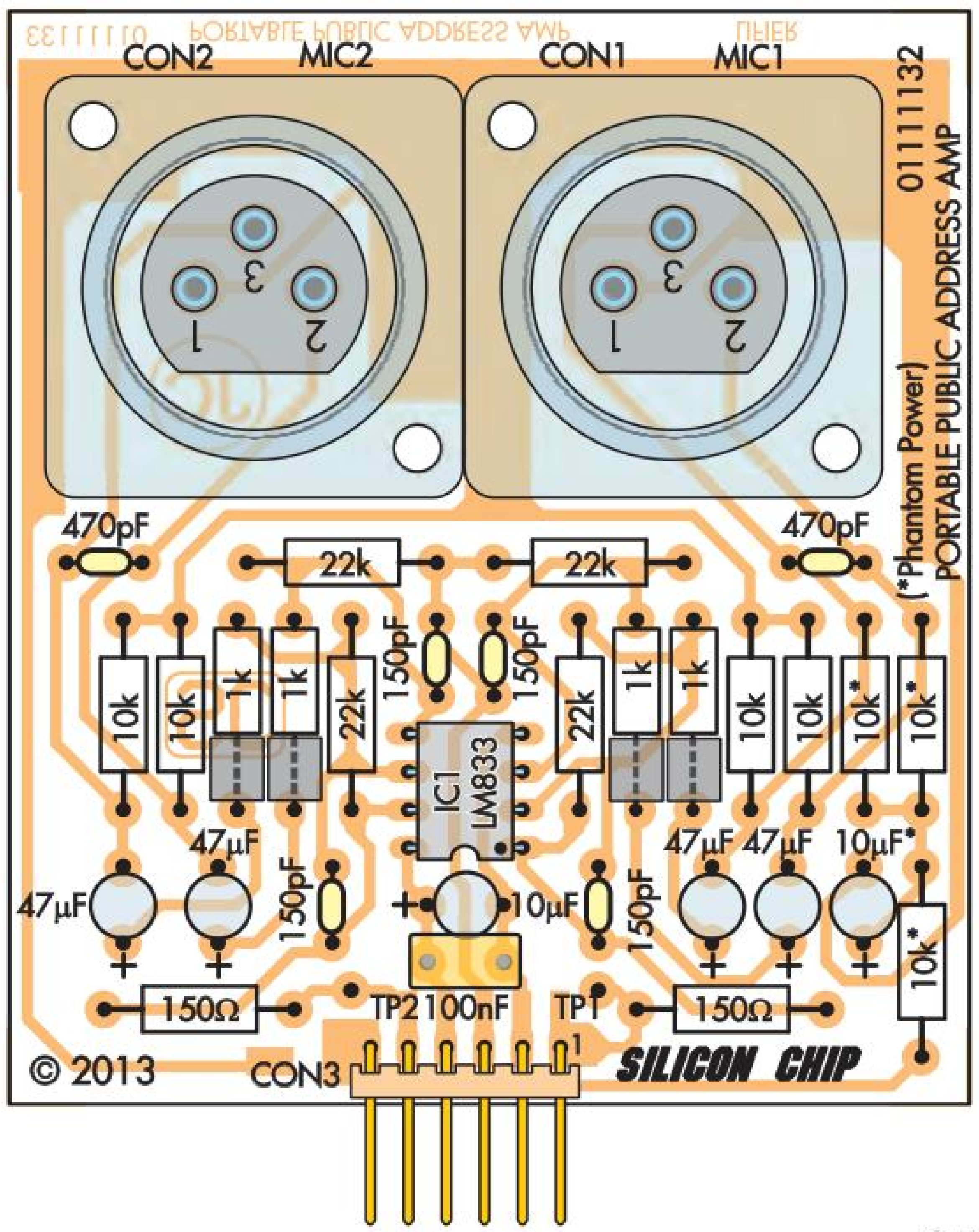
For the cutouts, we drilled a series of holes around the inside perimeter of the cutout, then filed it to shape.

In the absence of a metal bender, the 90° bends can be folded over the edge of a bench with the sheeting held in place with a timber block and clamps. A rubber mallet can be used to finish folding the aluminium flat along the bend crease.

After bending, you will have two L-shaped chassis pieces. One includes the front panel and onto this attaches the mixer, microphone and guitar PCBs and the charger. The second piece is for mounting the *CLASSiC-D Amplifier*, the *Speaker Protector*, the *DC-DC Converter*, the fan and the battery.

We attached two small cabinet handles 45mm long × 15mm high × 6mm wide to the edges of the front panel. This is to allow the panel to be more


SILICON CHIP PORTABLE PUBLIC ADDRESS AMP © 2013
01111133
150Ω
TP3
CON8
680pF
100nF
4.7k
IC2 TL071
10pF
2.2µF
47µF
47µF
10µF
10µF
10k
2.2k
2.2k
1k
1M
CON7
LINE OUT
CON6
LINE IN
CON5
CON4


CON2
MIC2
CON1
MIC1
01111132
PORTABLE PUBLIC ADDRESS AMP
(*Phantom Power)
470pF
470pF
22k
22k
10k
10k
1k
1k
22k
150pF
150pF
IC1 LM833
10k*
10k*
47µF
47µF
47µF
47µF
10µF*
10µF
150Ω
150Ω
TP2
100nF
TP1
© 2013
CON3
SILICON CHIP

Figs.6 and 7: component overlays for the guitar and line input PCB (above) and the microphone input PCB (right). The two boards mate to the main PCB via CON8 to CON10 and CON3 to CON11, respectively,

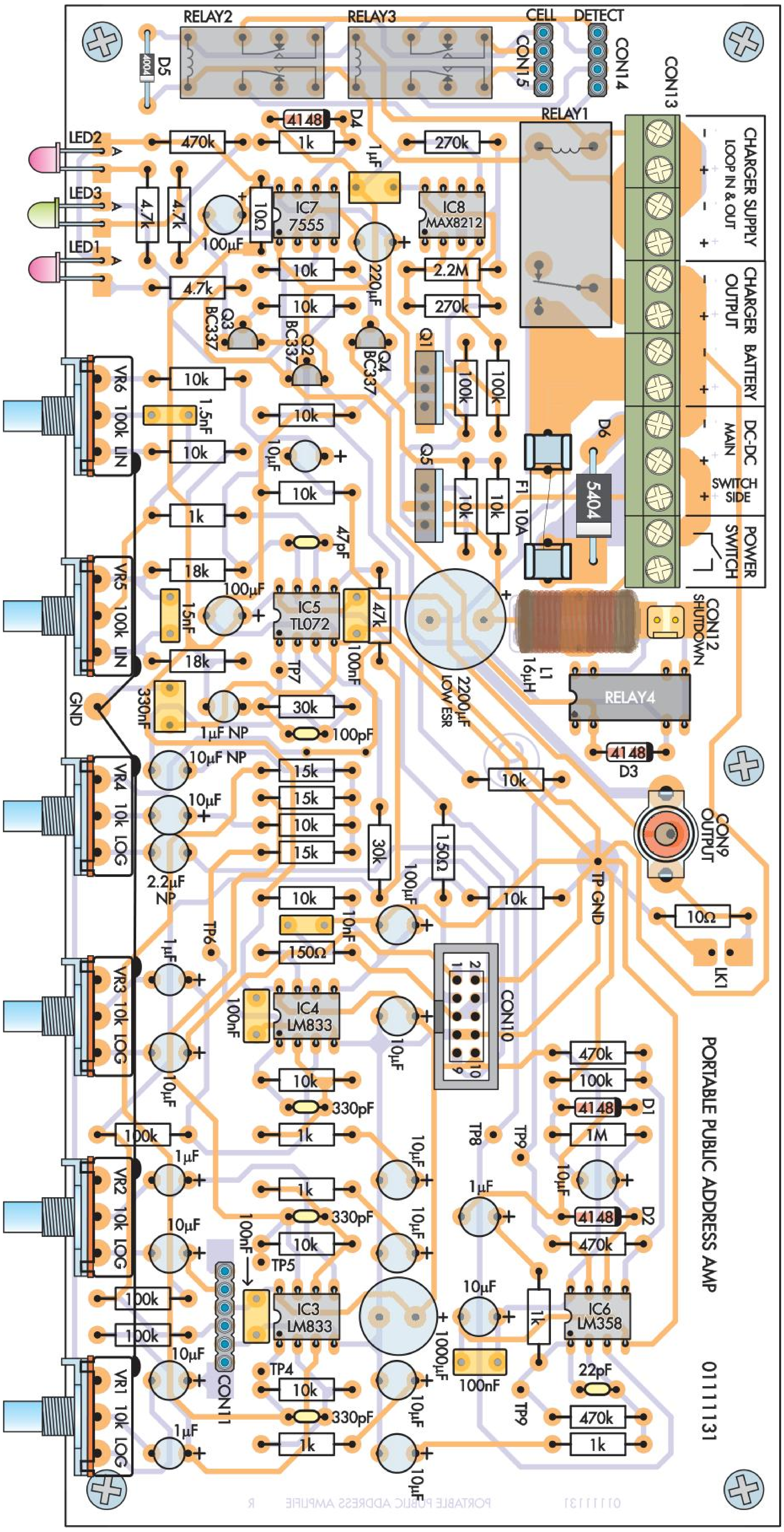

RELAY2
RELAY3
CELL
DETECT
CON15
CON14
CON13
RELAY1
D5
4004
4148
D4
LED2
LED3
LED1
A
470k
1k
270k
1µF
4.7k
10Ω
IC7
7555
IC8
MAX8212
100µF
10k
220µF
2.2M
Q3
BC337
Q2
Q4
Q1
100k
CHARGER SUPPLY
LOOP IN & OUT
CHARGER OUTPUT
BATTERY
DC-DC MAIN
SWITCH SIDE
POWER SWITCH
VR6 100k LIN
1.5nF
10µF
Q5
D6
5404
F1 10A
47pF
VR5 100k LIN
18k
15nF
IC5
TL072
47k
100nF
TP7
2200µF LOW ESR
L1 16µH
CON12 SHUTDOWN
RELAY4
GND
330nF
30k
1µF NP
100pF
10µF NP
D3
VR4 10k LOG
15k
150Ω
CON9 OUTPUT
2.2µF NP
TP GND
10Ω
LK1
TP6
VR3 10k LOG
IC4
LM833
CON10
330pF
470k
D1
TP8
TP9
1M
VR2 10k LOG
D2
TP5
IC3
LM833
IC6
LM358
1000µF
22pF
CON11
TP4
VR1 10k LOG
PORTABLE PUBLIC ADDRESS AMP
01111131

Fig.8: this board contains all of the mixing and audio signal control circuitry before it is passed off to the *CLASSiC-D Amplifier* module from CON9. It also contains the important power monitoring and processing circuitry to prevent damage to the Li-Po battery. These batteries, while light and powerful, are not quite as forgiving as other types if mishandled in the charging/discharging department.

easily removed from the loudspeaker cabinet. Our handles were fashioned by cutting the corner pillar sections from the base of a UB5 blue translucent box – but small drawer or cabinet handles, available from any hardware store, would be even better.

Brackets

Four aluminium brackets are required. These are made using 12 × 3mm aluminium bar.

Both the charger bracket and battery bracket have a heatshrink-tubing-covering to protect the charger and battery from direct contact with the aluminium that may otherwise short to the battery or damage the charger case.

Fig.12 shows the 110mm-long charger bracket. 3mm-diameter holes are drilled 104mm apart, with one hole being countersunk for the right-angle bracket. The aluminium is covered with a 95mm length of 10mm-diameter heatshrink tubing, shrunk down using a heat gun.

Fig.12 also shows how the charger bracket is used – one end has two 12mm lengths of M3-tapped spacers supported with an M3 × 20mm screw. This is held in the front panel with an M3 × 10mm screw. At the other end of the bracket, a right-angle bracket is attached using a countersunk screw. The right-angle section then mounts to the horizontal panel of the L-shaped panel that also holds the *CLASSiC-D Amplifier*.

Fig.13 shows the two frame brackets. These support the chassis junction between the top two mounting holes of the *CLASSiC-D Amplifier* PCB and two of the main mixer PCB mountings that are directly opposite from the amplifier. With good fortune, the same spacings are between the standoffs in the *CLASSiC-D Amplifier* and the main mixer. As shown in Fig.13, the brackets are 65mm long with 3mm diameter holes 55mm apart with a right angle bracket attached at one end.

For the battery bracket, the arrangement is shown in Fig.14. The bracket is 83mm long with holes 73mm apart. The bracket is covered with an 87mm-long length of 10mm heatshrink tubing. Two stacked 12mm, M3 tapped spacers are held at each end with M3 × 20mm screws. The bracket holds the battery in place with M3 countersunk screws into the *CLASSiC-D Amplifier* chassis along the horizontal panel.

Chassis assembly

For the front panel L-shaped chassis section, check that the mixer PCB fits correctly with the potentiometer and LEDs fitting into their allocated holes. The preamp mounts on 15mm tapped standoffs that are attached using six M3 × 6mm screws. These are only used along the rear of the PCB. The potentiometers support the PCB at the front.

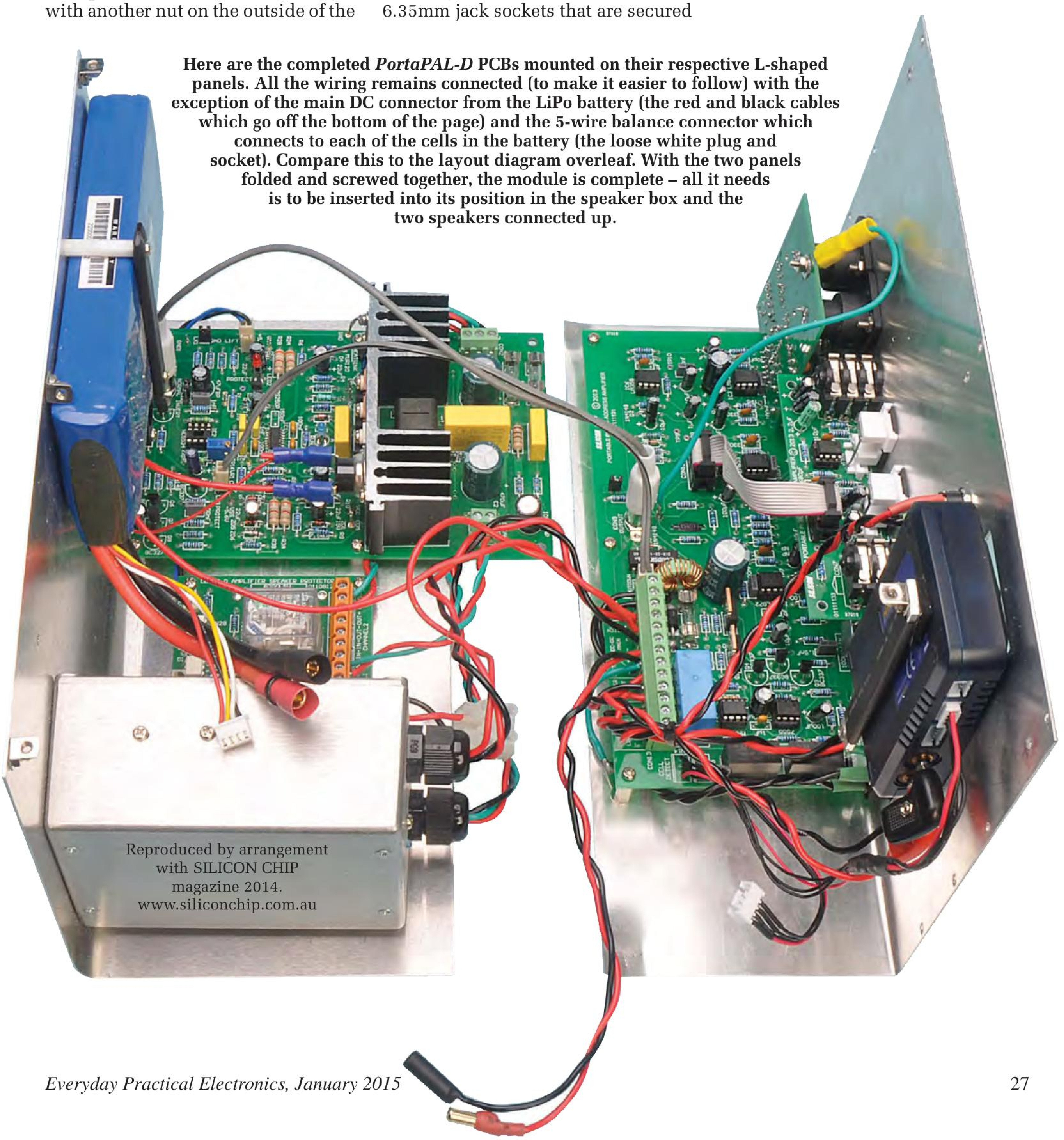
We placed a potentiometer nut on each potentiometer before securing it with another nut on the outside of the panel. This spaces the PCB back a little from the front panel.

Also check that the microphone input PCB and the guitar and line input PCBs fit correctly onto the front panel. The microphone PCB is plugged into the 6-way socket on the main mixer PCB and the XLR sockets fit into the holes in the panel. The PCB is supported in place using M3 screws or self-tapping screws into the XLR socket mounts.

The guitar PCB is held via the 6.35mm jack sockets that are secured to the panel with a nut. The RCA sockets are secured with self-tapping screws. Check also that the charger fits into its cut out.

Front panel

Once these fit correctly, the PCBs should be removed so that the front panel label can be attached. The front panel can be printed out from the file on the *EPE* website. We used A4 photo paper and adhered the printout to the panel with silicone sealant. The



Here are the completed *PortaPAL-D* PCBs mounted on their respective L-shaped panels. All the wiring remains connected (to make it easier to follow) with the exception of the main DC connector from the LiPo battery (the red and black cables which go off the bottom of the page) and the 5-wire balance connector which connects to each of the cells in the battery (the loose white plug and socket). Compare this to the layout diagram overleaf. With the two panels folded and screwed together, the module is complete – all it needs is to be inserted into its position in the speaker box and the two speakers connected up.

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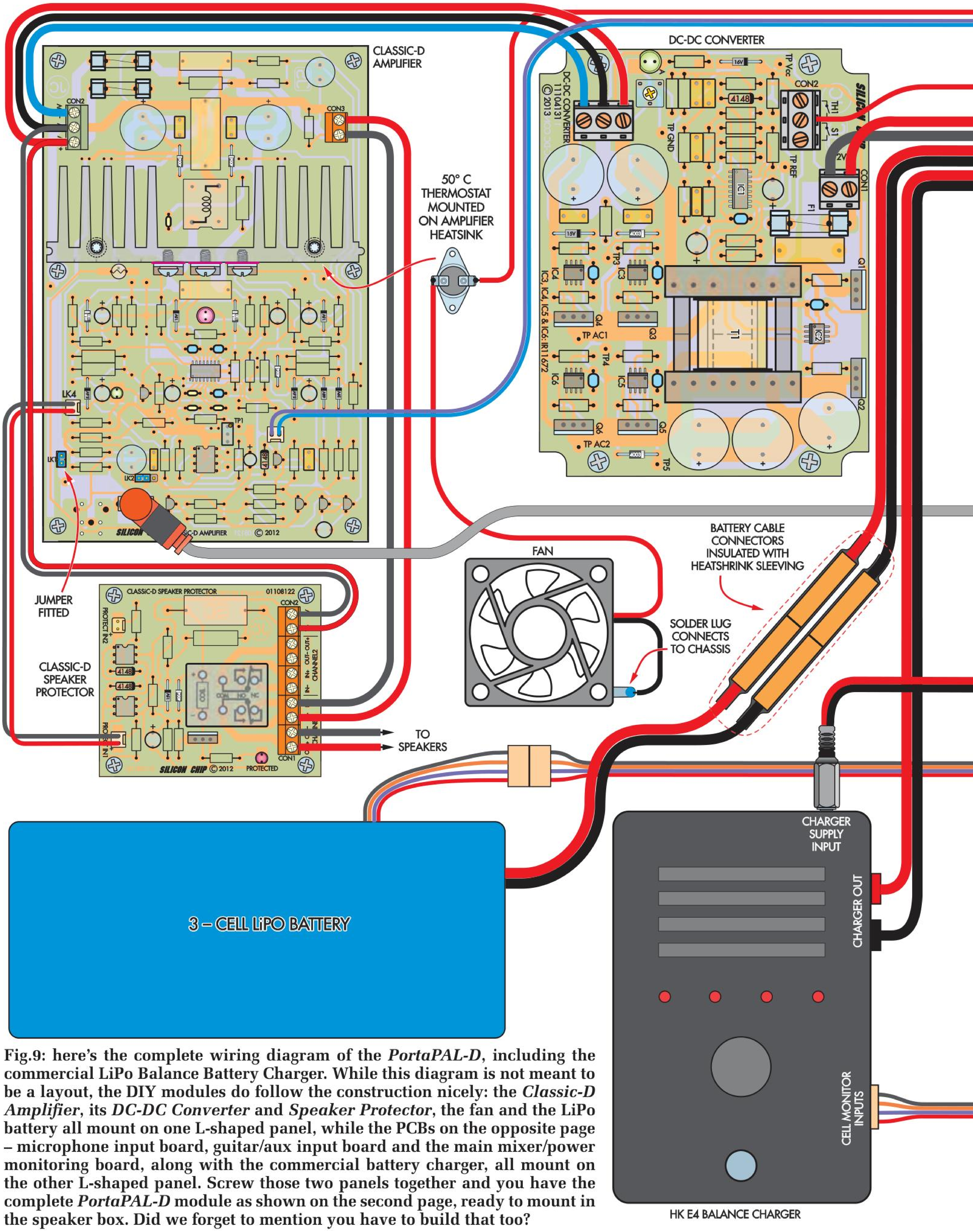
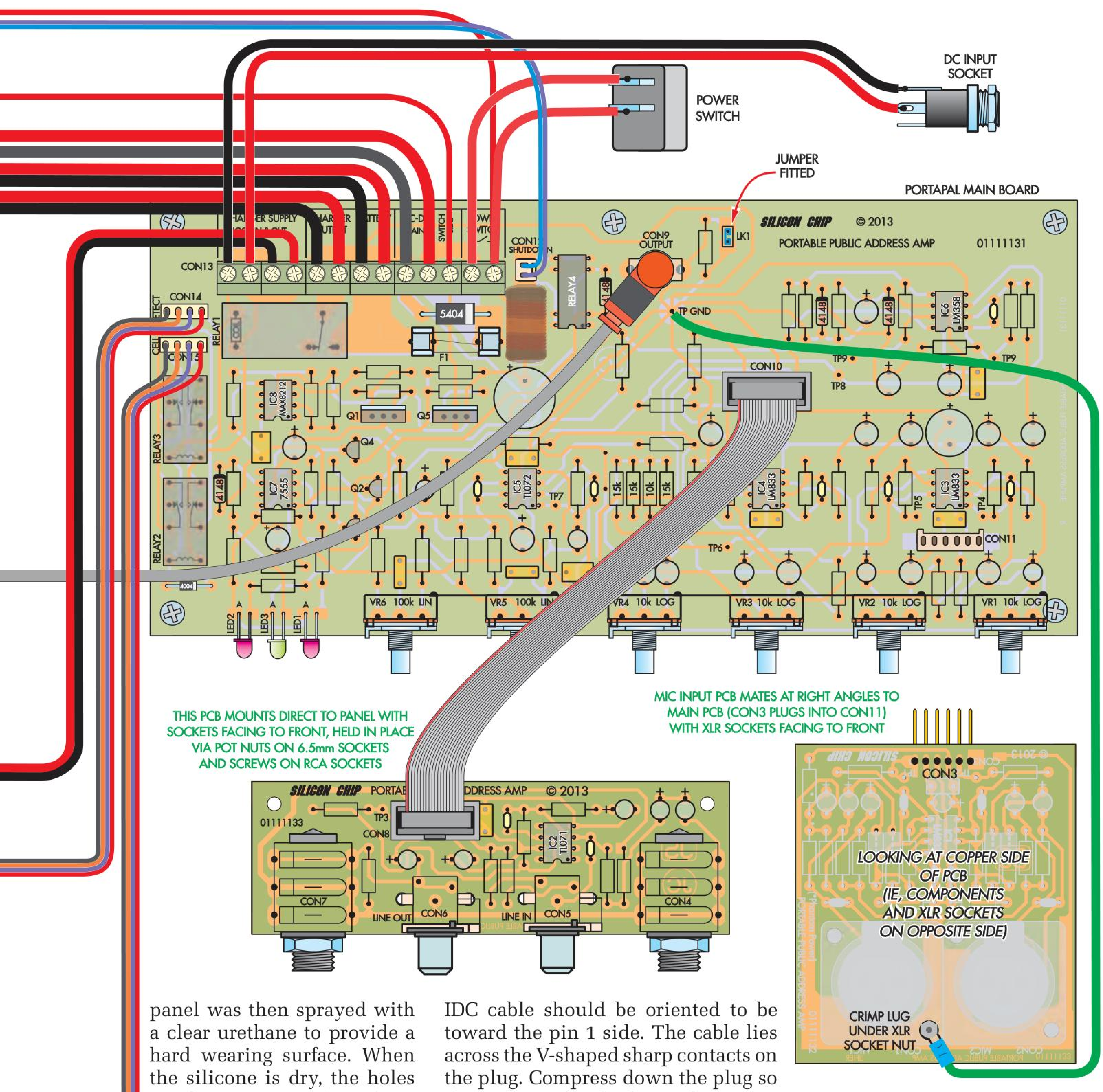

CLASSIC-D AMPLIFIER
CON2
CON3
50° C THERMOSTAT MOUNTED ON AMPLIFIER HEATSINK
LK4
TP1
LK1
LK2
SILICON CHIP
CLASSIC-D AMPLIFIER
© 2012
JUMPER FITTED
CLASSIC-D SPEAKER PROTECTOR
CLASSiC-D SPEAKER PROTECTOR
01108122
PROTECT IN2
PROTECT IN1
4148
4148
CHANNEL2
OUT- OUT+
IN+ IN-
CON1
PROTECTED
SILICON CHIP © 2012
TO SPEAKERS
DC-DC CONVERTER
DC-DC CONVERTER
11104131
© 2013
TP Vcc
16V
4148
CON2
TH1
S1
12V
CON1
TP GND
TP REF
IC1
F1
15V
4003
TP3
IC3, IC4, IC5 & IC6: IR11672
IC4
IC3
Q1
Q4
Q3
TP AC1
TP4
T1
IC2
IC6
IC5
Q2
Q6
Q5
TP AC2
4003
TP5
FAN
SOLDER LUG CONNECTS TO CHASSIS
BATTERY CABLE CONNECTORS INSULATED WITH HEATSHRINK SLEEVING
3 – CELL LiPO BATTERY
CHARGER SUPPLY INPUT
CHARGER OUT
CELL MONITOR INPUTS
HK E4 BALANCE CHARGER

Fig.9: here's the complete wiring diagram of the *PortaPAL-D*, including the commercial LiPo Balance Battery Charger. While this diagram is not meant to be a layout, the DIY modules do follow the construction nicely: the *Classic-D Amplifier*, its *DC-DC Converter* and *Speaker Protector*, the fan and the LiPo battery all mount on one L-shaped panel, while the PCBs on the opposite page – microphone input board, guitar/aux input board and the main mixer/power monitoring board, along with the commercial battery charger, all mount on the other L-shaped panel. Screw those two panels together and you have the complete *PortaPAL-D* module as shown on the second page, ready to mount in the speaker box. Did we forget to mention you have to build that too?


DC INPUT SOCKET
POWER SWITCH
JUMPER FITTED
PORTAPAL MAIN BOARD
SILICON CHIP © 2013
PORTABLE PUBLIC ADDRESS AMP 01111131
CON13
CON14
CON15
CON9 OUTPUT
CON10
CON11
TP GND
LK1
RELAY1
RELAY2
RELAY3
RELAY4
5404
F1
IC8 MAX8212
IC7 7555
IC5 TL072
IC4 LM833
IC3 LM833
IC6 LM358
Q1
Q2
Q4
Q5
VR6 100k LIN
VR5 100k LIN
VR4 10k LOG
VR3 10k LOG
VR2 10k LOG
VR1 10k LOG
LED1
LED2
LED3
THIS PCB MOUNTS DIRECT TO PANEL WITH SOCKETS FACING TO FRONT, HELD IN PLACE VIA POT NUTS ON 6.5mm SOCKETS AND SCREWS ON RCA SOCKETS
SILICON CHIP PORTABLE PUBLIC ADDRESS AMP © 2013
01111133
CON8
TP3
IC2 TL071
CON7
LINE OUT CON6
LINE IN CON5
CON4
MIC INPUT PCB MATES AT RIGHT ANGLES TO MAIN PCB (CON3 PLUGS INTO CON11) WITH XLR SOCKETS FACING TO FRONT
CON3
LOOKING AT COPPER SIDE OF PCB (IE, COMPONENTS AND XLR SOCKETS ON OPPOSITE SIDE)
CRIMP LUG UNDER XLR SOCKET NUT

panel was then sprayed with a clear urethane to provide a hard wearing surface. When the silicone is dry, the holes can be cut out with a sharp hobby knife.

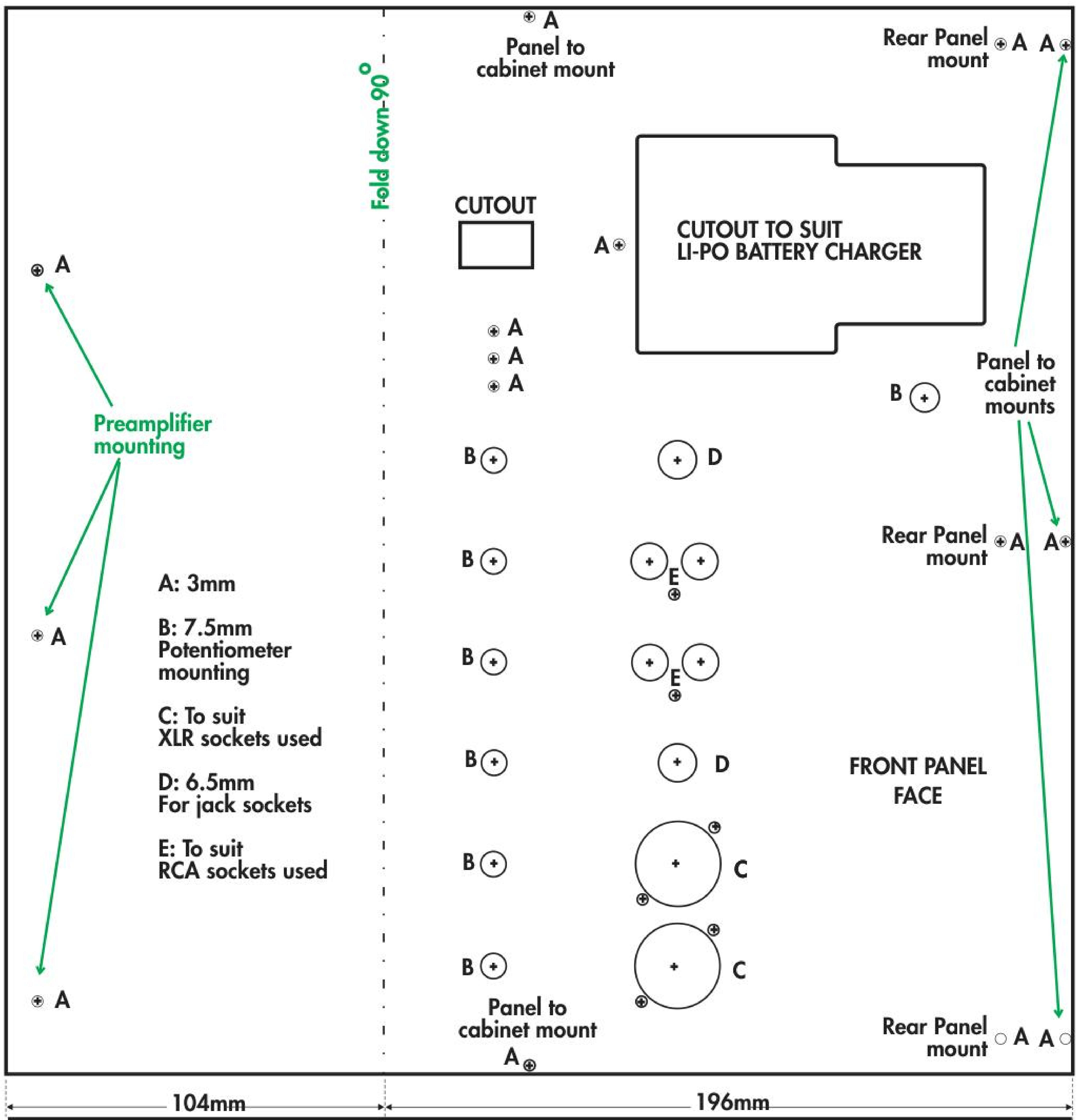
Reinstall the PCBs onto the panel. Take care not to damage the front panel while you are completing the wiring and chassis assembly.

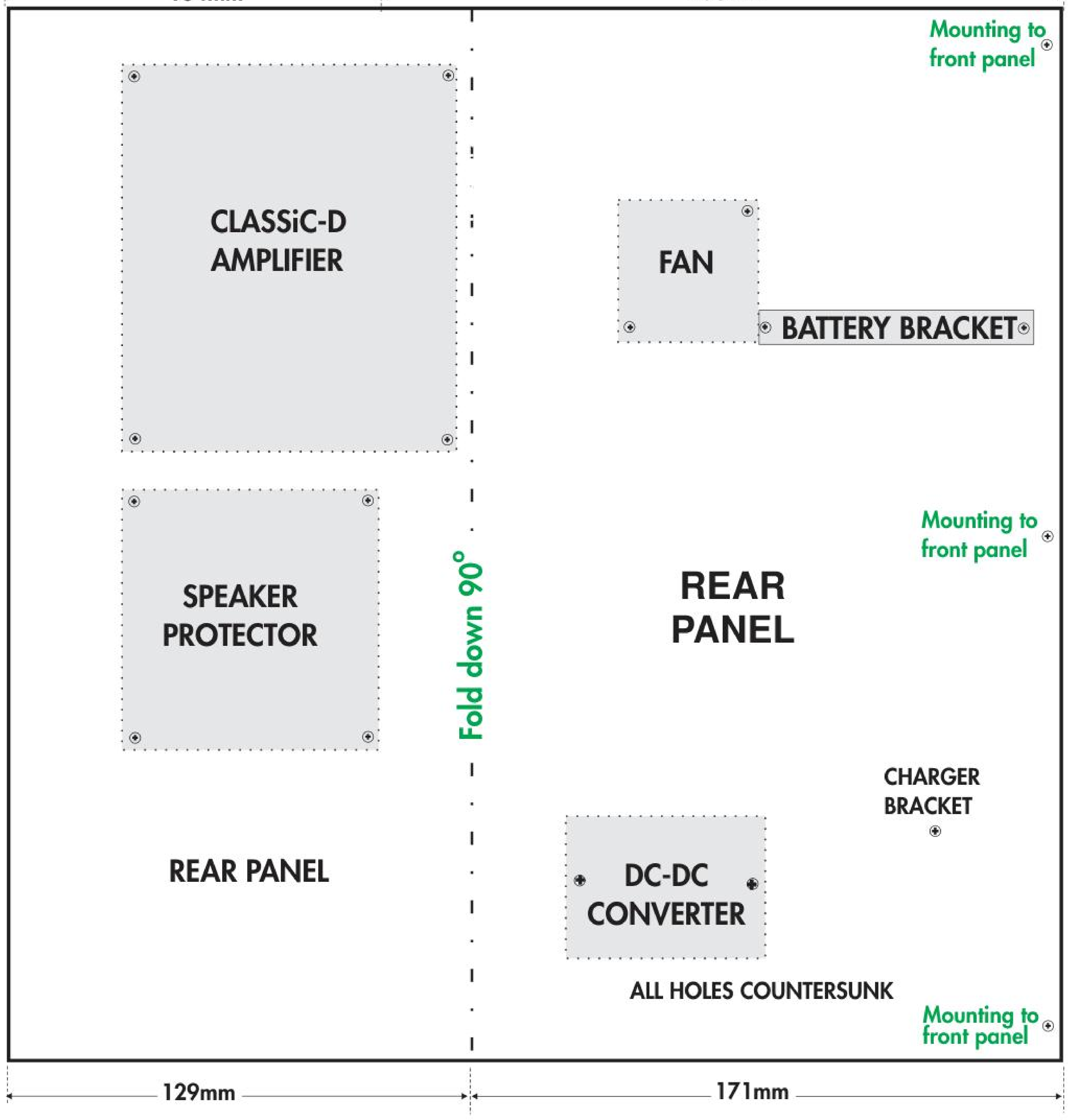
Make up the lead to connect the main mixer PCB to the guitar input PCB. This comprises two 10-way IDC line plugs and a 100mm length of 10-way IDC cable. The polarity indicator arrow on each plug is pin 1 and the red stripe side of the 10-way IDC cable should be oriented to be toward the pin 1 side. The cable lies across the V-shaped sharp contacts on the plug. Compress down the plug so the wires are pushed into these contacts. This cable can now be plugged into the sockets on the two PCBs.

The power switch, DC socket and charger unit can be installed now. Note that the charger can be partially held in place with the 24mm spacer end of the charger bracket attached to the front panel with an M3 screw. The other end of the bracket attaches to the *CLASSiC-D Amplifier* L-shaped chassis later on.

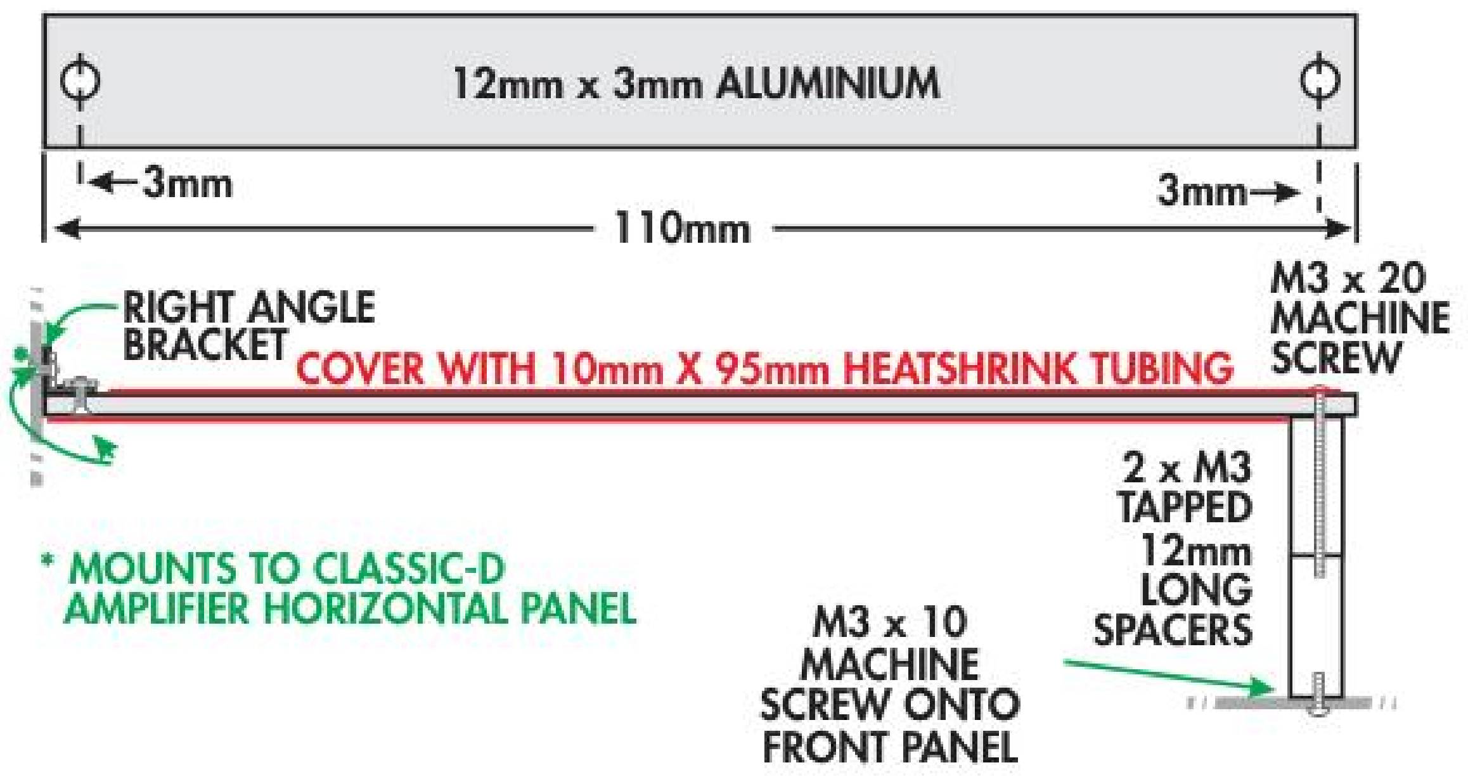
The *CLASSiC-D Amplifier* L-shaped chassis can be assembled now. The *CLASSiC-D Amplifier* and the *Speaker Protector* are each mounted on four M3 × 9mm standoffs using M3 × 10mm screws. Only the lower four mounts are used with the *CLASSiC-D Amplifier* PCB, the two mounting holes above the heatsink (where the power in and speaker terminals are located) are free from the chassis and attach to the chassis brackets.

The fan mounts onto two 12mm tapped spacers positioned diagonally from each other using two M3 × 10mm


A
Panel to cabinet mount
Rear Panel mount
A A
Fold down-90°
CUTOUT
A
CUTOUT TO SUIT LI-PO BATTERY CHARGER
A
A
A
A
B
Panel to cabinet mounts
Preamplifier mounting
B
D
Rear Panel mount
A A
B
E
A: 3mm
B: 7.5mm Potentiometer mounting
C: To suit XLR sockets used
D: 6.5mm For jack sockets
E: To suit RCA sockets used
A
B
E
B
D
FRONT PANEL FACE
B
C
B
C
A
Panel to cabinet mount
A
Rear Panel mount
A A
104mm
196mm


Mounting to front panel
CLASSiC-D AMPLIFIER
FAN
BATTERY BRACKET
SPEAKER PROTECTOR
Fold down 90°
Mounting to front panel
REAR PANEL
CHARGER BRACKET
REAR PANEL
DC-DC CONVERTER
ALL HOLES COUNTERSUNK
Mounting to front panel
129mm
171mm

Figs. 10 and 11 (left) show the sizes and drilling details for the two panels. These are reproduced here at 40% life size. Figs. 12, 13 and 14 (below and right) are details of the four brackets required. Much larger versions of these drawings, with more detail can be downloaded from the *EPE* website.


12mm x 3mm ALUMINIUM
3mm
110mm
3mm
RIGHT ANGLE BRACKET
COVER WITH 10mm X 95mm HEATSHRINK TUBING
M3 x 20 MACHINE SCREW
2 x M3 TAPPED 12mm LONG SPACERS
* MOUNTS TO CLASSiC-D AMPLIFIER HORIZONTAL PANEL
M3 x 10 MACHINE SCREW ONTO FRONT PANEL

CHARGER BRACKET – 1 REQUIRED

countersunk screws on the underside of the chassis. Two M3 × 15mm screws are used to secure the fan to the spacers.

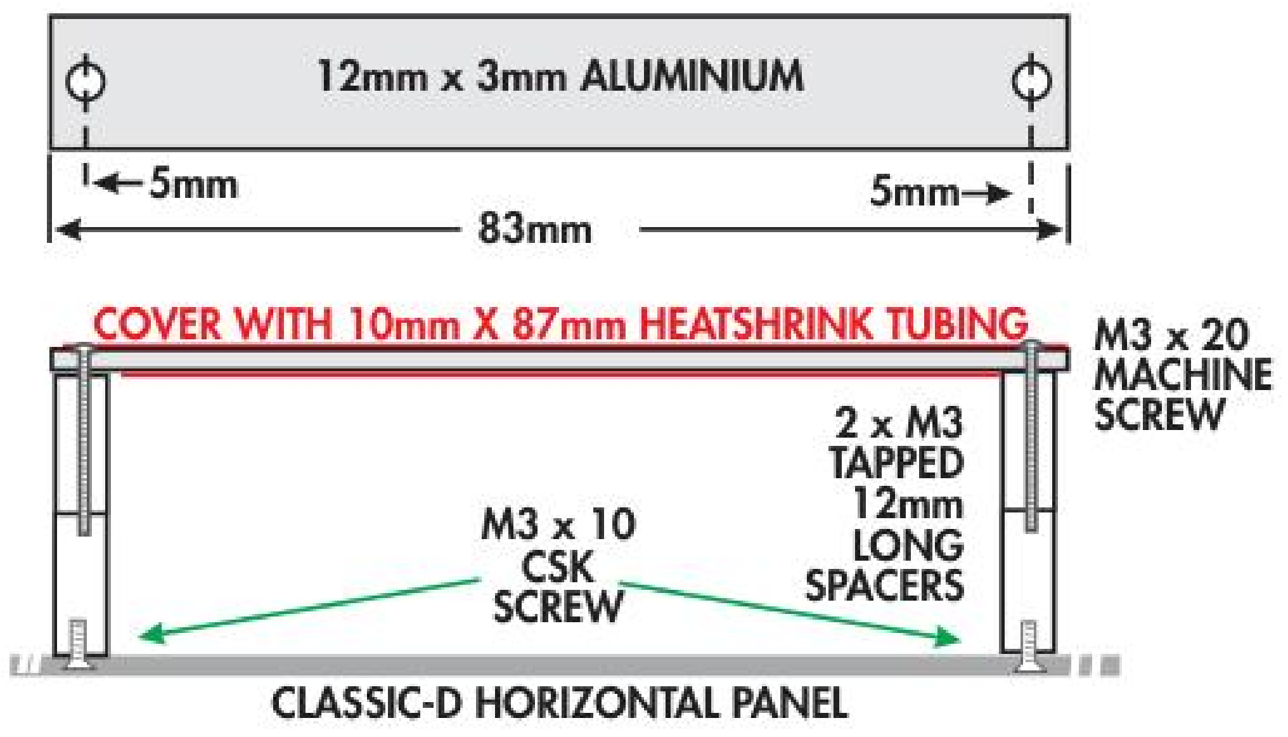
The *DC-DC Converter* mounts onto the chassis using two M3 × 6mm countersunk screws. Position the *DC-DC Converter* box over the two mounting holes and mark out on the box where the holes are to be drilled. Drill the two holes at 2.5mm (3/32-inch) in the box before tapping the thread with an M3 tap. Be sure to clean out any metal shavings from within the *DC-DC Converter* box.

The battery is secured in place using the battery clamp. Use M3 × 20mm screws to secure the two 12mm spacers to the bracket and M3 x 10mm countersunk screws to attach the spacers to the panel.

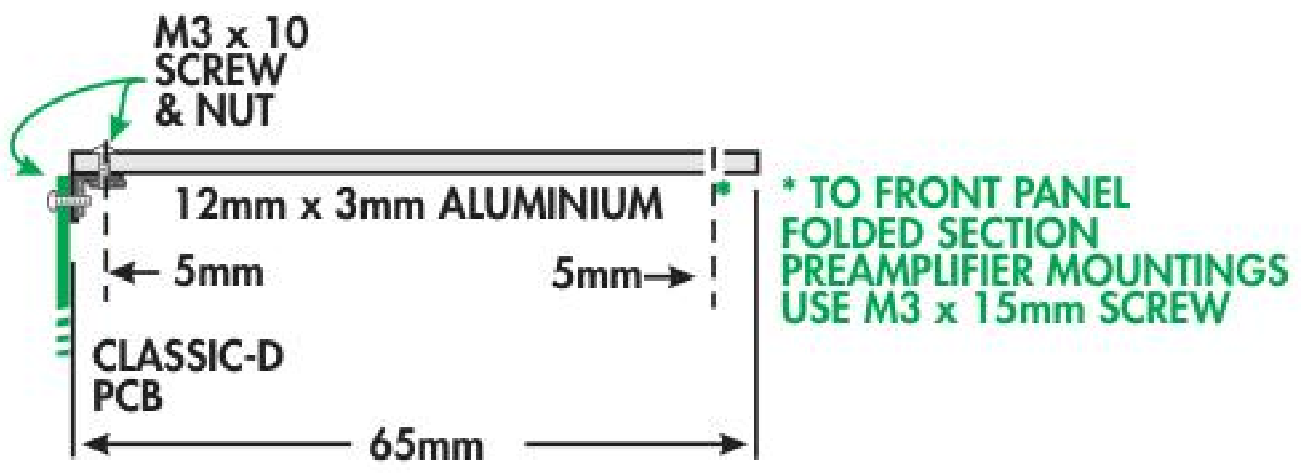
Wiring

Before assembling the two L-shaped chassis panels together, some of the wiring can be completed. For the *CLASSiC-D Amplifier* chassis, that means wiring can be done between the *DC-DC Converter* ±35V supply outputs and the *CLASSiC-D Amplifier* and *Speaker Protector,* plus interconnecting wires between the amplifier and the *Speaker Protector.* Fig.13 shows the wiring diagram.

Wires connecting to the power input of the *CLASSiC-D Amplifier* are held against the heatsink with a ‘P’ clamp. This helps to keep the wires away from internal cleats when the chassis is inserted in the speaker box. Most wiring is done using 7.5A-rated wire. Typically, the 0V wiring would be in black, positive wiring in red and earthing wiring in green. Using colour

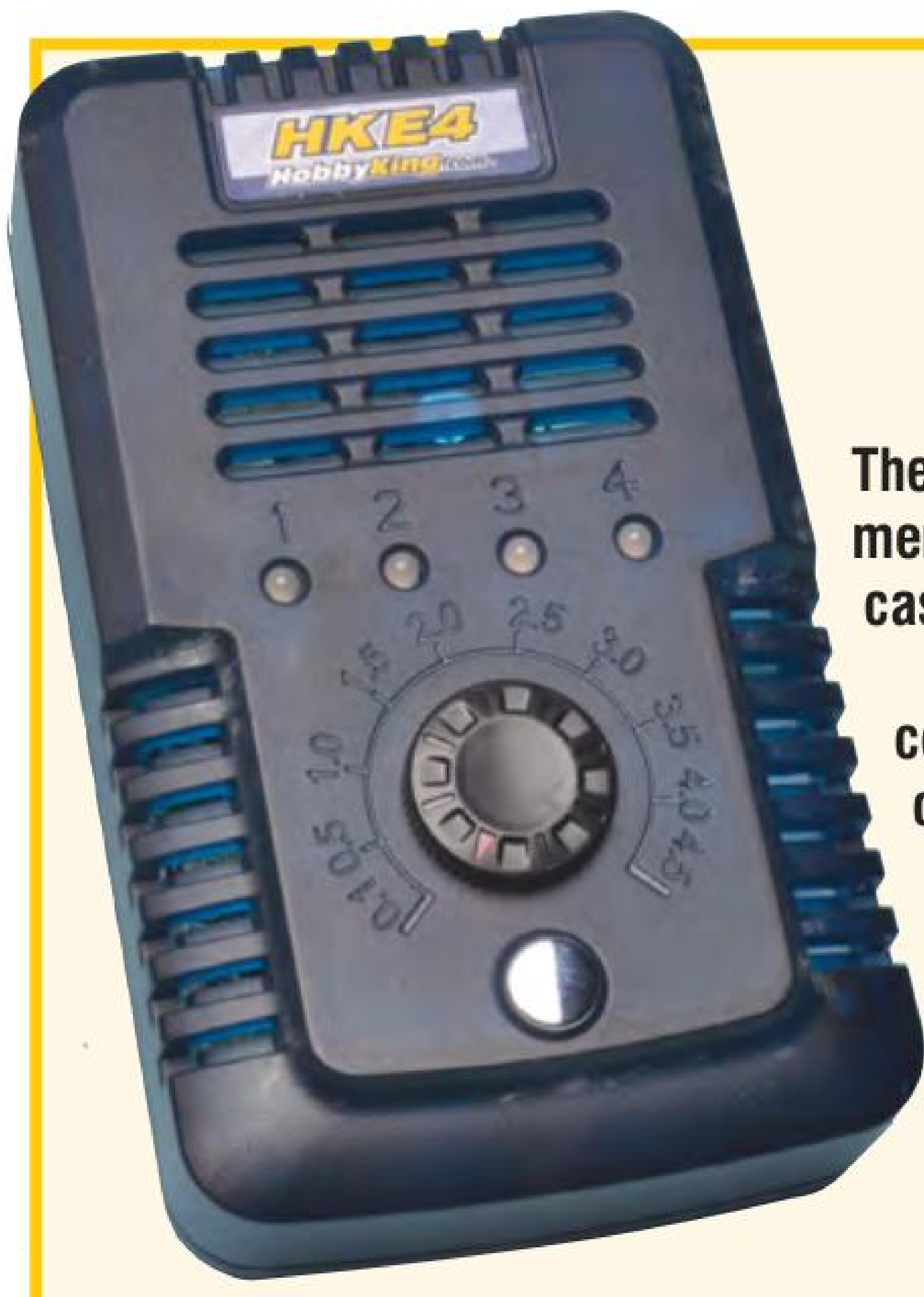

12mm x 3mm ALUMINIUM
5mm
5mm
83mm
COVER WITH 10mm X 87mm HEATSHRINK TUBING
M3 x 20 MACHINE SCREW
2 x M3 TAPPED 12mm LONG SPACERS
M3 x 10 CSK SCREW
CLASSIC-D HORIZONTAL PANEL

BATTERY BRACKET – 1 REQUIRED


M3 x 10 SCREW & NUT
12mm x 3mm ALUMINIUM
5mm
5mm
* TO FRONT PANEL FOLDED SECTION PREAMPLIFIER MOUNTINGS USE M3 x 15mm SCREW
CLASSIC-D PCB
65mm

FRAME BRACKET – 2 REQUIRED

LiPo battery charger


HKE4
HobbyKing
1
2
3
4
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

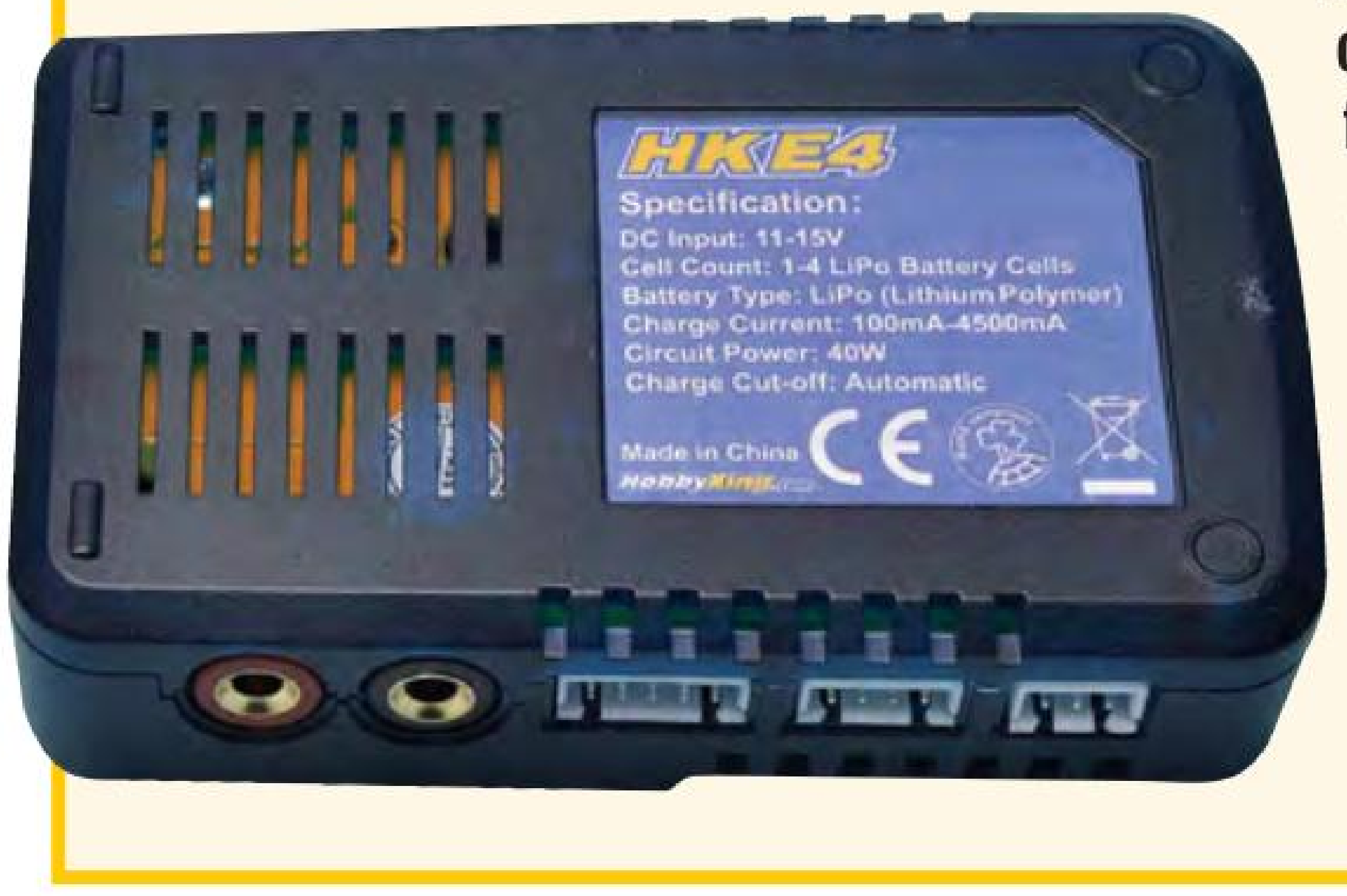
The battery charger we used for this project is a commercial unit which we mounted inside the PortaPAL-D case.

We can already hear the question: 'Why buy a commercial charger when you could have designed one and built it in?'

The answer is, quite simply, that we couldn't have hoped to build a battery charger for anything like the price of the HobbyKing TE4 Balance Charger (www.hobbyking.com). At time of writing, it sold for around £10.

This particular charger handles from 1-4 Lithium Polymer cells with an auto charge current of between 100mA and 4500mA from a DC input of 11-15V. Furthermore, as its name suggests, it automatically balances the charge on each of the cells (which accounts for the direct connection to those cells).

The lower photo shows the output connectors (large red and black terminals) along with the balance terminals for 2, 3 or 4 Lithium Polymer cells.


HKE4
Specification:
DC Input: 11-15V
Cell Count: 1-4 LiPo Battery Cells
Battery Type: LiPo (Lithium Polymer)
Charge Current: 100mA-4500mA
Circuit Power: 40W
Charge Cut-off: Automatic
Made in China
HobbyKing
CE

conventions helps to ensure the correct power polarity is connected.

The protect lead, comprising a 2-way lead with 2-pin header sockets on each end, plugs into the Protect IN1 plug on the *Speaker Protector* and LK4 on the *CLASSiC-D Amplifier*.

Wiring the fan to the thermostat can also be done. Fan wiring involves securing a solder lug under one of the spacer supports against the chassis and soldering the black fan lead to this. The red positive lead from the fan connects to the thermostat. The second thermostat terminal is the positive supply lead for the fan. This and the supply leads for the *DC-DC Converter* can be prepared ready to connect to the main mixer PCB.

Two other leads can also be prepared. One is the 150mm length of single-core screened cable that has an RCA line plug connected to each end: one end is plugged into the *CLASSiC-D Amplifier* input RCA socket, while the other end is ready for connection to the main mixer PCB RCA outlet. The second is a 270mm length of twin figure-8 light gauge wire with a 2-pin header socket on each end. This lead connects to the LK3 protect header on the *CLASSiC-D Amplifier*, while the other end connects to the main mixer PCB at the shutdown connector CON12.

Front panel chassis wiring is mainly for the charger and battery plus the interconnecting wires to the other *CLASSiC-D Amplifier* chassis. Wires connect from the power switch itself to the power switch terminals on the mixer PCB. For the charger, a 2.5mm DC line plug connects to the charger supply input on the charger and the wires connect charger supply out terminals on the main mixer PCB.

The charger supply input terminals on the mixer PCB connect to the 2.5mm DC panel connector. Charger output terminals on the mixer PCB connect to the charger output on the charger itself using right-angle banana plugs. Red is for positive and black for the negative plug.

Battery supply terminals on the mixer PCB connect to leads that are terminated into Polymax 5.5mm gold connectors. The negative lead is terminated into the socket and the positive lead is terminated into the plug. These are designed to plug into the plug and socket leads on the battery.

Note that it is important to place heatshrink tubing over the plug and socket so that when connected to the battery terminals, there is no exposed metal. The leads as supplied with the battery have their terminals excessively covered in protective heatshrink tubing. It will be necessary to remove the excess tubing covering the plug portion of the negative lead plug and directly at the end of the red positive lead socket to expose the socket. You can connect up the 4-way cell sensing plug and socket to the battery and charger but do not connect the battery terminals yet.

There are two earthing wires. One is from the battery minus terminal on the main mixer PCB to the chassis. The second is from the microphone input PCB that connects to the TP GND PC stake on the main mixer PCB.

The two L-shaped chassis sections can now be connected together. The base of the *CLASSiC-D Amplifier* chassis piece connects to the front panel using right angle brackets. The *CLASSiC-D Amplifier* PCB's top mounting holes are attached to the frame brackets using right-angle brackets. The opposite end of the frame brackets attach to the same screws that secure the main mixer PCB to its chassis.

Connect the supply and switch wiring to the *DC-DC Converter* and plug the RCA plug lead into the RCA output on the mixer PCB. Also connect the 2-pin header socket lead to the CON12 shutdown header.

NEXT MONTH

We'll build the PortaPAL-D box, cover it in speaker carpet, fit the speakers and then fit the PortaPAL-D module to the box to finish it off. In the meantime, you have plenty of work to do!

More reception modes for the SiDRADIO and SDRs

By JIM ROWE

Wondering if there's anything else you can do with your software defined radio (SDR) set-up using a DVB-T dongle – besides receiving AM, NFM, WFM, CW, SSB and DRM? Other applications are becoming available all the time. Already there's one that lets you receive DAB+ digital radio and another to receive some of the many different types of narrowband digital mobile radio (DMR).

MOST DVB-T dongles come with bundled software that allows them to be used for receiving SDTV and HDTV signals, as well as DAB+ digital radio and conventional FM signals. But if you're using a dongle as part of an SDR set-up, it's a bit messy to also use it for DTV/DAB+ reception on the same PC. That's because you have to disconnect it and plug it into a different USB port from the one you are using for the SDR.

This is necessary because the USB driver for DTV/DAB+/FM reception using the bundled software is quite different from the one that Zadig installs for use with SDR software. Fortunately, there is a way around this problem.

What we are going to do here is show you how to get DAB+ reception while leaving the dongle as part of an SDR configuration (or even as part of the *SiDRADIO* described in the October – December 2014 issues). In other words, you will no longer have to unplug the dongle and plug it into a different USB port. All you have to do is install and run some additional software.

Now it's true that most of the DVB-T dongles use the Realtek RTL2832U COFDM demodulator chip, which already has internal 'hardware' to decode DAB+ digital radio signals. In fact, this function is used by the bundled software that comes with the dongles.

However, so far, the programmers working on SDR applications haven't discovered how to make use of this internal hardware of the RTL2832U chip. Instead, they use the RTL-SDR driver (installed by Zadig) to switch the chip into its 'radio' mode. In this mode, it simply passes on the quadrature (I and Q) samples coming from the dongle's tuner chip and sends them to the PC via a USB cable. It's here that the SDR application software (SDR#, ADSB#, Dream or whatever) does the decoding/demodulation.

Eventually, someone is bound to work out how to make use of the RTL2832U chip's 'internal decoding hardware' for DAB+ reception and more. But until then, you're going to have to use the 'software decoding' approach, if we want to receive DAB+ transmissions with dongle-based SDRs such as the *SiDRADIO*.

Receiving DAB+

As luck would have it, a public domain software package which allows DAB+ signals to be received using a DVB-T dongle-based SDR has been made available. Called 'SDR-J' and released by Dutch programmer Jan van Katwijk, the latest version (V0.96 at the time of writing) is available as a free download from his website at: **www.sdr-j.tk**

Two versions of SDR-J are available: (1) a Linux version (as a suite of source code files) and (2) a Windows version, which consists of a zip file containing the executables. Note, however, that the heavy processing requirements of DAB+ software decoding mean that you need a relatively modern computer to run it. Also, the Windows version is currently only suitable for 64-bit versions of Windows 7 or Windows 8.

If you're running a 32-bit version of Windows, you'll still have to use your dongle's bundled software for DAB+ reception – at least for the time being. Assuming you're running a 64-bit version of Windows, you might want to try downloading and installing SDR-J V0.96 to see how it performs. While you're downloading the software, you should also download Jan van Katwijk's user manual from: **www.sdr-j.tk/dab-manual.pdf**

As mentioned, the software comes as a zip file. To extract the files, you have to run **dabreceiver.exe.** This should install everything 'ready to go' and you'll find a shortcut icon on your desktop labelled 'DAB RADIO'.

When you double click this icon, you'll first see a command line dialog box open up – just like the one shown at the top of Fig.1. This box will display the actions of SDR-J's software 'engine' as it proceeds. After a short time, it will be joined by a second window similar to the lower one in Fig.1. This is the control panel for SDR-J, although both it and the command line dialog box are displayed all the time that SDR-J is running.

To begin using SDR-J, check the four rectangular buttons at lower left in the control panel window, just below the black ‘constellation’ display window at upper left. Look first at the button at far left and if it is not displaying ‘dabstick’ as shown in Fig.1, click on the associated down arrow and select ‘dabstick’ from the drop-down menu.

Next, move along to the third button and confirm that SDR-J is currently set to look for DAB+ signals in BAND III (again, as shown in Fig.1). If not, click on its down-arrow and select BAND III from the drop-down menu.

Before going further, check that Band III channel(s) are being used for DAB+ broadcasts in your area. Up to 18 different DAB+ signals can be multiplexed onto a single DRMT ‘channel’ and each channel is 1.536MHz wide. Just how many DAB+ signals are packaged into each DRMT channel block depends on the data bit rate used by each one.

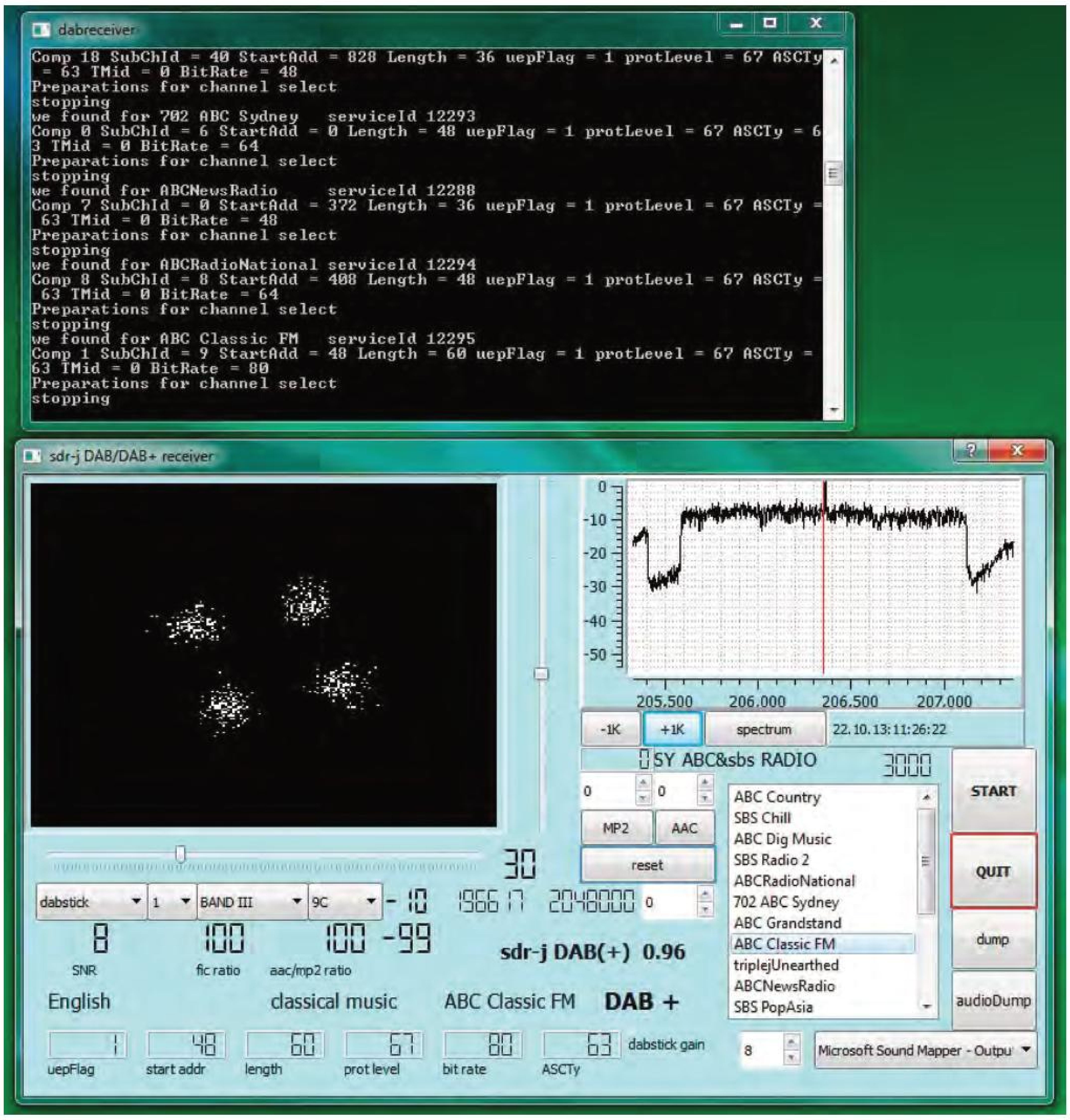
Once you know which DRMT channels are present in your area, you can continue setting up SDR-J. First, click the down-arrow associated with the fourth button at lower left and select the channel you want from the drop-down menu. Fig.1 shows that channel 9C has been selected in our case.

Then click the large START button at centre right of the control panel and SDR-J will start searching for DAB+ signals in the selected channel and you should see each of the signals it finds in the ‘list box’ just to the left of the START and QUIT buttons.

Fig.1 shows some of the signals found within channel 9C in Sydney in the list box. It also shows the spectrum display that SDR-J has produced for Sydney channel 9C DAB+ multiplex, ie, in the spectrum box at upper right of the control panel window.

Next, look at the long rectangular button at bottom right on the control panel, which initially will probably be labelled ‘select output’. Click on its down arrow and select one of the options from the drop-down menu. In most cases, this will be an audio output device like ‘Microsoft Sound Mapper – Output’ or ‘Speakers (Realtek High Definition)’.

Then click on one of the entries shown in the list box, to select it. You should then see some activity in SDR-J’s upper command-line dialog, while it achieves synchronisation with that signal. Finally, after a few seconds, you should hear that signal’s audio from your PC’s speakers. And that’s all there is to it!



```
Comp 18 SubChId = 40 StartAdd = 828 Length = 36 uepFlag = 1 protLevel = 67 ASCTy
 = 63 TMid = 0 BitRate = 48
Preparations for channel select
stopping
we found for 702 ABC Sydney   serviceId 12293
Comp 0 SubChId = 6 StartAdd = 0 Length = 48 uepFlag = 1 protLevel = 67 ASCTy = 6
3 TMid = 0 BitRate = 64
Preparations for channel select
stopping
we found for ABCNewsRadio     serviceId 12288
Comp 7 SubChId = 0 StartAdd = 372 Length = 36 uepFlag = 1 protLevel = 67 ASCTy =
 63 TMid = 0 BitRate = 48
Preparations for channel select
stopping
we found for ABCRadioNational serviceId 12294
Comp 8 SubChId = 8 StartAdd = 408 Length = 48 uepFlag = 1 protLevel = 67 ASCTy =
 63 TMid = 0 BitRate = 64
Preparations for channel select
stopping
we found for ABC Classic FM   serviceId 12295
Comp 1 SubChId = 9 StartAdd = 48 Length = 60 uepFlag = 1 protLevel = 67 ASCTy =
63 TMid = 0 BitRate = 80
Preparations for channel select
stopping
```

dabstick | 1 | BAND III | 9C | -10 | 196617 | 2048000 | 0

SNR 8 | fic ratio 100 | aac/mp2 ratio 100 -99 | 30

sdr-j DAB(+) 0.96

English | classical music | ABC Classic FM | DAB +

uepFlag 1 | start addr 48 | length 60 | prot level 67 | bit rate 80 | ASCTy 63 | dabstick gain 8

SY ABC&sbs RADIO 3000

22.10.13:11:26:22

Fig.1: SDR-J first opens up a command line dialog box, followed by a second control panel window. Both are displayed while ever SDR-J is running.

If you want to change to another station in the same multiplex, all you need do is click on it in the list box. After a few seconds delay, you’ll then start to hear the audio from that station.

Other DRMT multiplexes

What if you want to search for signals in one of the other DRMT multiplexes in your area? That’s also quite easy. All you need do is select the channel ID for the multiplex you want (eg, say 9A or 9B) by clicking on the down-arrow at the end of the fourth button at lower left. SDR-J will then generate a new list of DAB+ stations (ie, the stations associated with that multiplex) in the list box and show a new spectrum display at upper right. Then all you need to do to receive a station is click on its name in the list box, as before.

Other controls

What about all of those other controls and displays scattered around SDR-J’s control panel? Jan van Katwijk’s user manual isn’t all that helpful when it comes to many of these, so you will have to work them out for yourself. But some are fairly self-evident if you look at them closely – or at their label, where they have one.

For example, in the lower centre of the control panel shown in Fig.1, you’ll see SDR-J’s title: ‘sdr-j DAB(+) 0.96’. And below this you can see the name of the station I had tuned to: ‘ABC Classic FM DAB+’, with its programming language and summary shown to the left.

Just above the SDR-J title, you can see two numbers, displayed in 7-segment format: 196617 and 2048000. The first of these apparently indicates the length of the data frames detected in the multiplex signal (it should normally read about 196617, as shown), while the second shows the total bit rate used in that multiplex. The latter always seems to read 2048000, suggesting a total bit rate of 2.048Mbps.

Just above the list box, you can also see the label ‘SY ABC&sbs RADIO’, which is presumably the name of the DRMT multiplex signal itself.

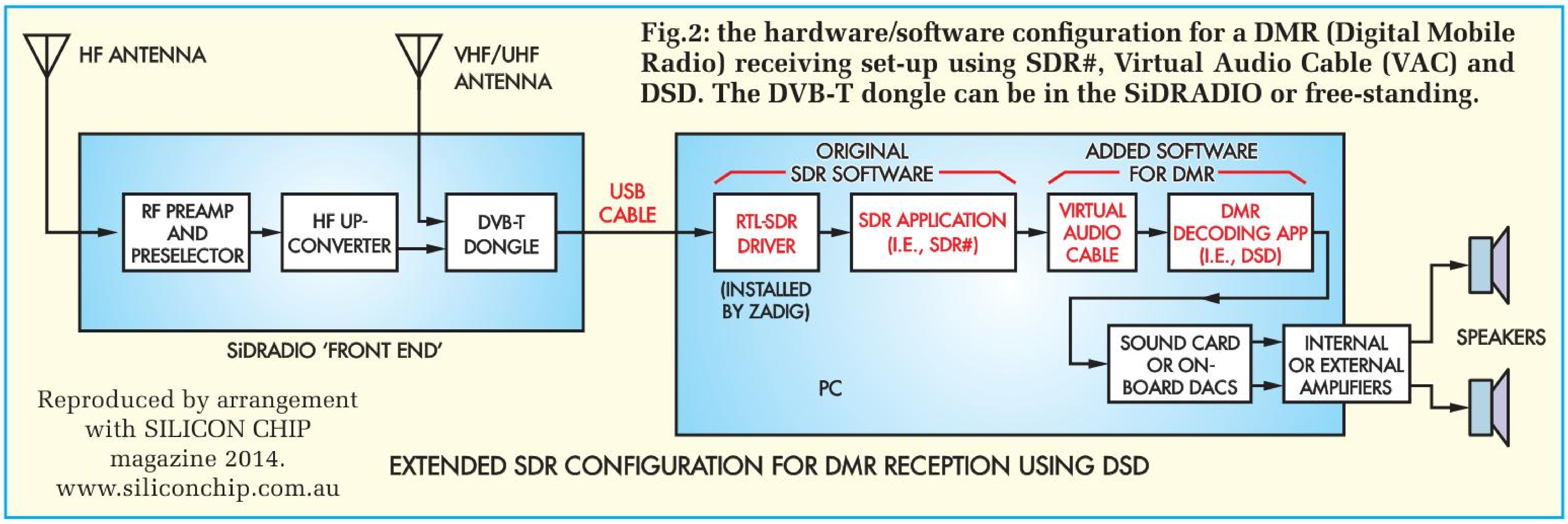

HF ANTENNA
VHF/UHF ANTENNA
RF PREAMP AND PRESELECTOR
HF UP-CONVERTER
DVB-T DONGLE
SiDRADIO 'FRONT END'
USB CABLE
ORIGINAL SDR SOFTWARE
ADDED SOFTWARE FOR DMR
RTL-SDR DRIVER
(INSTALLED BY ZADIG)
SDR APPLICATION (I.E., SDR#)
VIRTUAL AUDIO CABLE
DMR DECODING APP (I.E., DSD)
SOUND CARD OR ON-BOARD DACS
INTERNAL OR EXTERNAL AMPLIFIERS
SPEAKERS
PC
EXTENDED SDR CONFIGURATION FOR DMR RECEPTION USING DSD

Fig.2: the hardware/software configuration for a DMR (Digital Mobile Radio) receiving set-up using SDR#, Virtual Audio Cable (VAC) and DSD. The DVB-T dongle can be in the SiDRADIO or free-standing.

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At lower right, just to the left of SDR-J's 'Output Select' button, there's a small box displaying a single digit ('8' in Fig.1). Just to its left, there's a label reading 'dabstick gain' and if you click on one or other of the small direction arrows on its right, you'll find that the spectrum display moves up or down as the displayed gain digit increases or decreases.

This seems to be the way SDR-J allows you to adjust the RF gain of your DVB-T dongle, for optimum DAB+ reception (presumably 'dabstick' is what DVB-T dongles are called in many parts of Europe).

One last suggestion: the row of display boxes at bottom left has fairly cryptic labels, making it difficult to work out their significance unless you're an expert on DAB+. However, the 'bit rate' label just below the fifth one from the left suggests that it shows the bit rate of the particular signal in the multiplex currently being decoded. In this case, it's showing '80', while the third last line in the command line box above also shows 80 as the bit rate of the ABC Classic FM signal being received at the time.

This means that ABC uses a bit rate of 80kbps for this signal, which is encoded using the HE-AAC compression codec.

Receiving DMR

OK, so much for using SDR-J to receive DAB+ broadcasts. Now let's take a brief look at yet another application for SDRs based on a DVB-T dongle.

Professional 2-way radio communications is rapidly making the transition from analogue-to-digital technology. This is because digital encoding offers more efficient use of the spectrum, allowing more users to be crammed into limited spectrum space.

So narrowband 2-way radio is fast becoming 'DMR' or digital mobile radio. That may sound simple, but the catch is that there are many different digital encoding formats and modulation modes. These can make it quite difficult to receive and decode DMR signals – especially as many of the formats allow for the signals to be encrypted or scrambled for high security communications, like those of the military, intelligence services and police.

For example, there's NXDN or Next Generation Digital Narrowband technology, developed jointly by Icom and JVC Kenwood. This allows two 6.25kHz wide narrowband digital channels to be fitted into a single 12.5kHz wide VHF communications channel.

Then there's Project 25 (P25/APCO-25), a suite of digital radio communications formats which were developed in the US to allow reliable and secure 2-way radio communications within specific federal and state government agencies and between these agencies.

Another variant is the set of protocols developed by the European Telecommunications Standards Institute (ETSI) for professional DMR, or 'PMR'. There's also Motorola's DMR/MOTOTRBO, ProVoice EDACS, and so on.

Fortunately, an open source software package recently became available to allow a DVB-T-based SDR set-up to receive and decode at least some of this plethora of DMR formats and modulation systems. Called Digital Speech Decoder or 'DSD' for short, it can decode the following DMR formats and modulation types (providing they're not encrypted):

- P25 Phase 1
- ProVoice EDACS digital voice
- NXDN – 9600-baud/12.5kHz NEXEDGE and 4800-baud/6.25kHz NEXEDGE/IDAS
- X2-TDMA – Motorola public safety TDMA
- DMR/MOTOTRBO
- C4FM modulation, GFSK modulation and QPSK/LSM modulation

The DSD package can be downloaded from: **http://wiki.radioreference.com/index.php/Digital_Speech_Decoder_(software_package)** The version you'll need in order to run DSD on Windows PCs is currently called 'Windows Port With P25/DMR Filter 1.6.0 Beta'.

When you download this file, you'll find it's an executable called **DSD160.exe**, which you can install simply by creating a folder called (say) **C:\Program Files\DSD\** and then copying **DSD160.exe** over into it.

Don't try to run it yet though, because DSD was originally written to run under Linux. As a result this Windows 'port' needs a special Linux emulation program in order to actually run on Windows. This emulation program is an application extension called **cygwin1.dll**, which is part of a suite of programs you need to download and install separately from: **http://cygwin.com/install.html**

All you need to do is go to this page and click on the link **setup-x86.exe** (note: there's another link called **setup-x86_64.exe** but this is not needed for running DSD because the latter is a 32-bit package).

When the Cygwin package has been downloaded and installed (it automatically installs itself in the root directory, usually **C:\cygwin\**), you'll find the all-important **cygwin1.dll** file in the **\bin** subdirectory. The next step is to copy this file and paste it into the same folder as DSD itself (ie, **C:\Program Files\DSD\**).

Note that this program doesn't communicate directly with your DVB-T

Software for SDR applications using DVB-T dongles and where to find it

A. For basic SDR (AM, WFM, NFM, CW-L, CW-U, USB, LSB, DSB reception) you'll need:

(1) The RTL-SDR driver, which is installed using the installer program Zadig. A compressed file containing Zadig can be downloaded from **sourceforge.net/projects/libwdi/files/Zadig** but note that (a) there are two versions of Zadig, one for Windows XP and the other for Windows 7; and (b) both versions can only be downloaded as compressed files in '.7z' format, so they must be extracted using 7-Zip rather than Winzip.

7-Zip can be downloaded from either **sourceforge.net** or from **www.7-zip.org** but note that it too comes in two versions – one for Windows XP and the other for Windows 7.

(2) An SDR decoding and display application, such as SDR#. This is open source and comes in three separate files – two of which can be downloaded from **http://sdrsharp.com/downloads**, while the third (rtlsdr.dll) must be downloaded from the Osmocom website at **http://sdr.osmocom.org/trac/wiki/rtl-sdr/**

For more information on downloading, installing and using these basic SDR software components, refer to our article in the December 2014 issue of *EPE*.

B. For receiving, decoding and displaying the ADS-B broadcasts from aircraft flying overhead, you'll need:

(1) the RTL-SDR driver which is installed using the installer program Zadig (see item A.1 above).

(2) An ADS-B decoding application like ADSB# or RTL1090. These are both open source and ADSB# can be downloaded from **http://sdrsharp.com/downloads/adsbsharp.zip**

There's also a quickstart guide for ADSB# written by Henry Forte and available as a pdf file from **http://www.atouk.com/wordpress/?p=247** The RTL1090 application can be downloaded from **http://rtl1090.web99.de/**

(3) An ADS-B processing and display application like ADSBScope, Virtual Radar Server or PlaneSpotter. ADSBScope can be downloaded from **http://www.sprut.de/electronic/pic/projekte/adsb_en.html#downloads**; Virtual Radar Server from **http://www.virtualradarserver.co.uk**; and PlaneSpotter from **http://www.coaa.co.uk/planespotter.htm**

C. For receiving and listening to DRM (Digital Radio Mondiale) signals, and decoding them via RTL-SDR, you'll need:

(1) The RTL-SDR driver which is installed using the installer program Zadig (see item A.1 above).

(2) An SDR decoding and display application such as SDR# (see item A.2 above).

(3) A 'virtual audio cable' program like Virtual Audio Cable (VAC), to direct the digital audio output from SDR# to the input of the DRM decoding application. Virtual Audio Cable can be downloaded from either **software.muzychenko.net/vac.htm** or **download.cnet.com/Virtual_Audio_Cable**

(4) A DRM decoding/receiver application, like DREAM. This open source application can be downloaded from **sourceforge.net/projects/drm/files/dream/** You will also need the precompiled **faad2_drm.dll**, which is used for DRM decoding using the AAC codec. This must be downloaded from: **https://mega.co.nz/#!m5RUHIDQ!SqcGUBSGMFSTAm09XX78RDYRoIJW0T545QQRJ_dFuE**

For more information on downloading, installing and using these software components, see the article in the December 2014 issue of *EPE*.

D. For receiving and listening to DAB+ digital radio broadcasts as described in this article, you'll need:

(1) A PC running a 64-bit version of Windows 7 or Windows 8.

(2) The Windows version of the DAB+ receiving application SDR-J V0.96, developed by Dutch programmer Jan van Katwijk and available free from his website at **www.sdr-j.tk** There's also a user manual for it at **www.sdr-j.tk/dab-manual.pdf**

E. For receiving and listening to digital mobile radio (DMR) transmissions, as described in this article, you'll need:

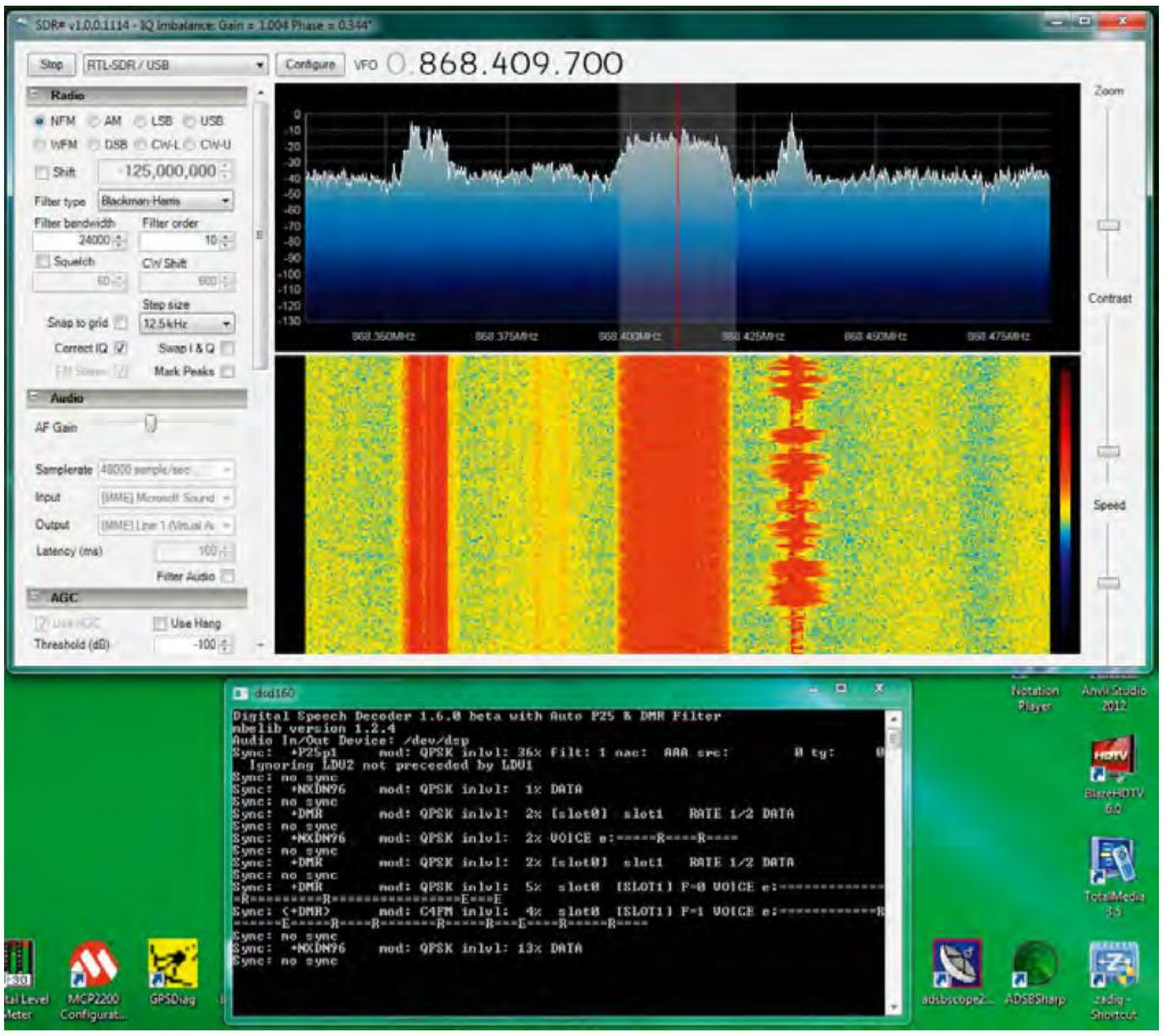
(1) The RTL-SDR driver which is installed using the installer program Zadig (see item A.1 above).

(2) An SDR decoding and display application such as SDR# (see item A.2 above).

(3) A 'virtual audio cable' program like Virtual Audio Cable, to direct the digital audio output from SDR# to the input of the DMR decoding application (see item C.3 above).

(4) A digital speech decoder application like Digital Speech Decoder (DSD). This is an open source program and can be downloaded from **http://wiki.radioreference.com/index.php/Digital_Speech_Decoder_(software package)#Downloads** The version to download for PC's running Windows is currently 'Windows Port with P25/DMS Filter 1.6.0 Beta'.

(5) The Linux emulation layer **cygwin1.dll**, which is needed by Digital Speech Decoder (DSD) to run on Windows systems. This can be downloaded from **http://cygwin.com/install.html** by clicking on the link '**setup-x86.exe**'.


SDR# v1.0.0.1114 - IQ Imbalance: Gain = 1.004 Phase = 0.344°
Stop
RTL-SDR / USB
Configure
VFO
868.409.700
Radio
NFM
AM
LSB
USB
WFM
DSB
CW-L
CW-U
Shift
125,000,000
Filter type
Blackman-Harris
Filter bandwidth
24000
Filter order
10
Squelch
CW Shift
Step size
12.5kHz
Snap to grid
Correct IQ
Swap I & Q
Mark Peaks
Audio
AF Gain
Samplerate
48000 sample/sec
Input
Output
[MME] Line 1 (Virtual A
Latency (ms)
100
Filter Audio
AGC
Use Hang
Threshold (dB)
-100
Zoom
Contrast
Speed
868.350MHz
868.375MHz
868.400MHz
868.425MHz
868.450MHz
868.475MHz
dsd160
MCP2200 Configurat...
GPSDiag
adsbscope2...
ADSBSharp
zadig - Shortcut
TotalMedia 3.5
BlazeHDTV 6.0
Notation Player
Anvil Studio 2012

```
Digital Speech Decoder 1.6.0 beta with Auto P25 & DMR Filter
mbelib version 1.2.4
Audio In/Out Device: /dev/dsp
Sync:  +P25p1     mod: QPSK inlvl: 36% filt: 1 nac:  AAA src:        0 tg:     0
  Ignoring LDU2 not preceeded by LDU1
Sync: no sync
Sync:  +NXDN96    mod: QPSK inlvl:  1% DATA
Sync: no sync
Sync:  +DMR       mod: QPSK inlvl:  2% [slot0]  slot1   RATE 1/2 DATA
Sync: no sync
Sync:  +NXDN96    mod: QPSK inlvl:  2% VOICE e:=====R====R====
Sync: no sync
Sync:  +DMR       mod: QPSK inlvl:  2% [slot0]  slot1   RATE 1/2 DATA
Sync: no sync
Sync:  +DMR       mod: QPSK inlvl:  5%  slot0  [SLOT1] F=0 VOICE e:============
=R=========R=================E===E
Sync: (+DMR)      mod: C4FM inlvl:  4%  slot0  [SLOT1] F=1 VOICE e:===========R
=====E=====R====R=======R=====R===E====R=====R====
Sync: no sync
Sync:  +NXDN96    mod: QPSK inlvl: 13% DATA
Sync: no sync
```

Fig.3: a typical DMR signal as shown in the spectrum and waterfall displays of SDR#. Note that you have to select Virtual Audio Cable (VAC) as the output option (see text) to send the signal to the PC for software decoding.

dongle via the RTL-SDR driver. Instead, it 'listens' to the digital audio output from your SDR application (eg, SDR#). In order to do this it needs Virtual Audio Cable (VAC), the same miniport digital audio driver used by Dream.

So before you can run DSD, you'll need to download and install both SDR# and VAC – and perhaps even the RTL-SDR driver, if you haven't already done so.

Fig.2 shows the overall hardware/software configuration for a DMR (Digital Mobile Radio) receiving set-up using SDR# plus VAC plus DSD. Note that although this diagram shows the DVB-T dongle fitted inside our *SiDRADIO* project, the dongle can be free-standing for DMR reception if you wish. That's because you'll only find DMR signals on the VHF and UHF bands at the moment.

Receiving DMR – or trying

The procedure for using your SDR set-up to receive DMR is to first start up SDR# with its digital audio going to your PC's speakers in the usual way. This allows you to search around on the VHF and UHF bands for any likely-looking signals.

By the way, it's a good idea to set SDR# for NFM reception, with a filter bandwidth of either 12.5kHz or 25kHz. Some of the reference information on DMR reception also suggests that the Filter Order should be set to a low figure, such as 10, instead of the default 300 or 400.

Search around on one of these bands using SDR# until you find a signal that looks a bit like that in the centre of the display in Fig.3. If it's a DMR signal, you won't hear any audio at this stage apart from digital noise.

Next, click the Stop button at top left in the SDR# dialog and then move down to the Output label in the Audio section below. If you now click on the down-arrow in the text box to its right, you will be presented with a drop-down list showing 'Virtual Audio Cable' (VAC) as one of the output options. If you click this option, SDR# will now send its digital audio output to VAC instead of the speakers.

Before you set SDR# running again, fire up DSD by clicking on its icon on your desktop. You'll then see its command-line interface, with the heading 'dsd160' – see Fig.3.

Now when you click the 'Play' button at top left in the SDR# dialog, you'll probably see some activity in the DSD dialog box as well. Just what you'll see in the DSD dialog depends on what type of signal you've tuned to, its signal strength, the DMR encoding system being used, the modulation mode and whether or not the signals are encrypted/scrambled.

The same qualifications apply as to whether or not you'll hear any audio. In my case, I spent quite a few hours trying to find a DMR signal that I could decode with very little success. I did receive a few seconds of audio on one occasion, but that was it.

In fact, my impression is that a lot of the DMR signals nominally available in my area are either encrypted or 'locked up' in trunking systems.

There is an open-source program called 'UniTrunker', which is supposed to allow you to decode some kinds of trunked DMR. You can download it from **http://wiki.radioreference.com/index.php/UniTrunker** but I can't say whether or not it's worth the effort. In my opinion, it's for the real enthusiast only and you'd better have a lot of patience!

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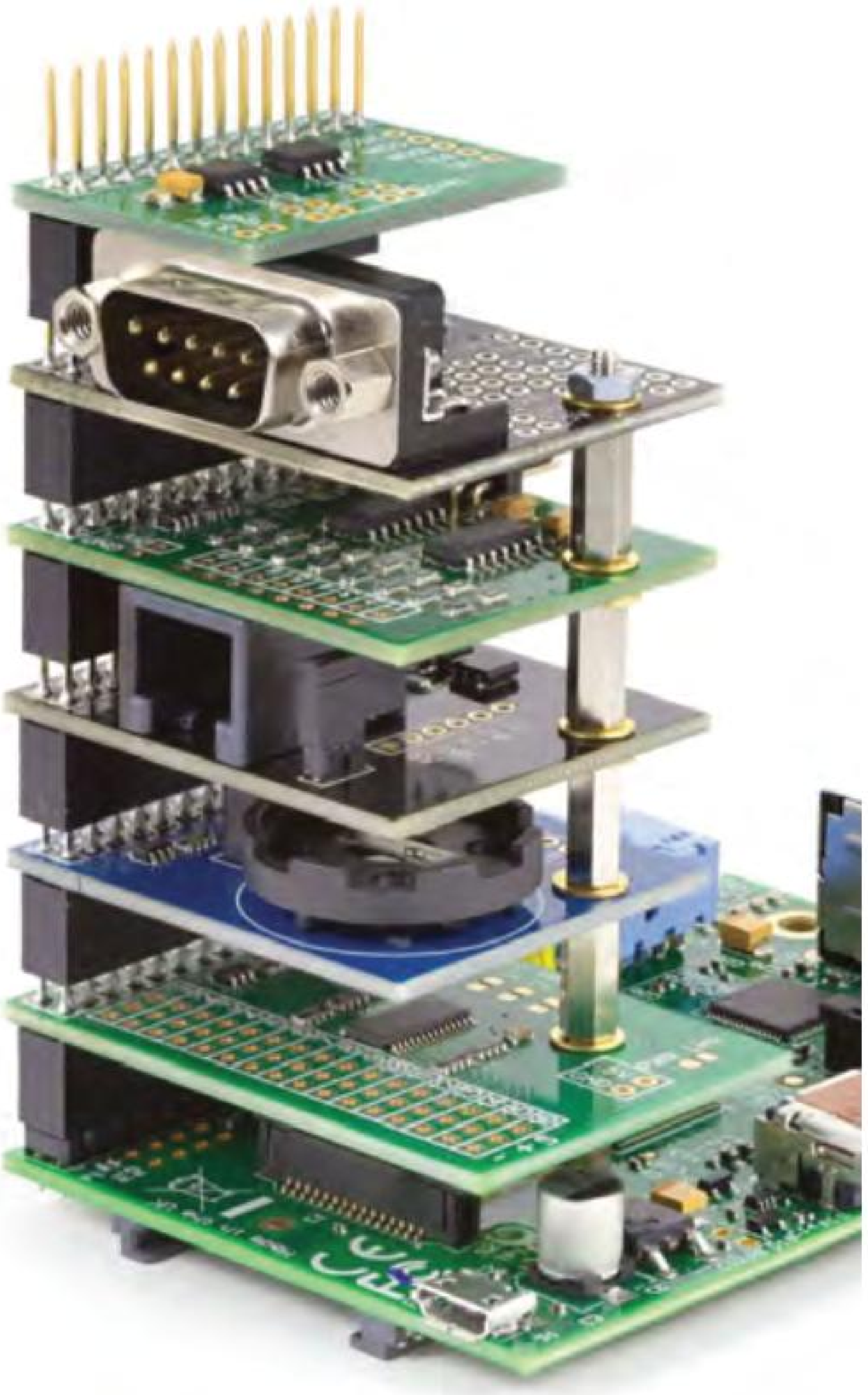

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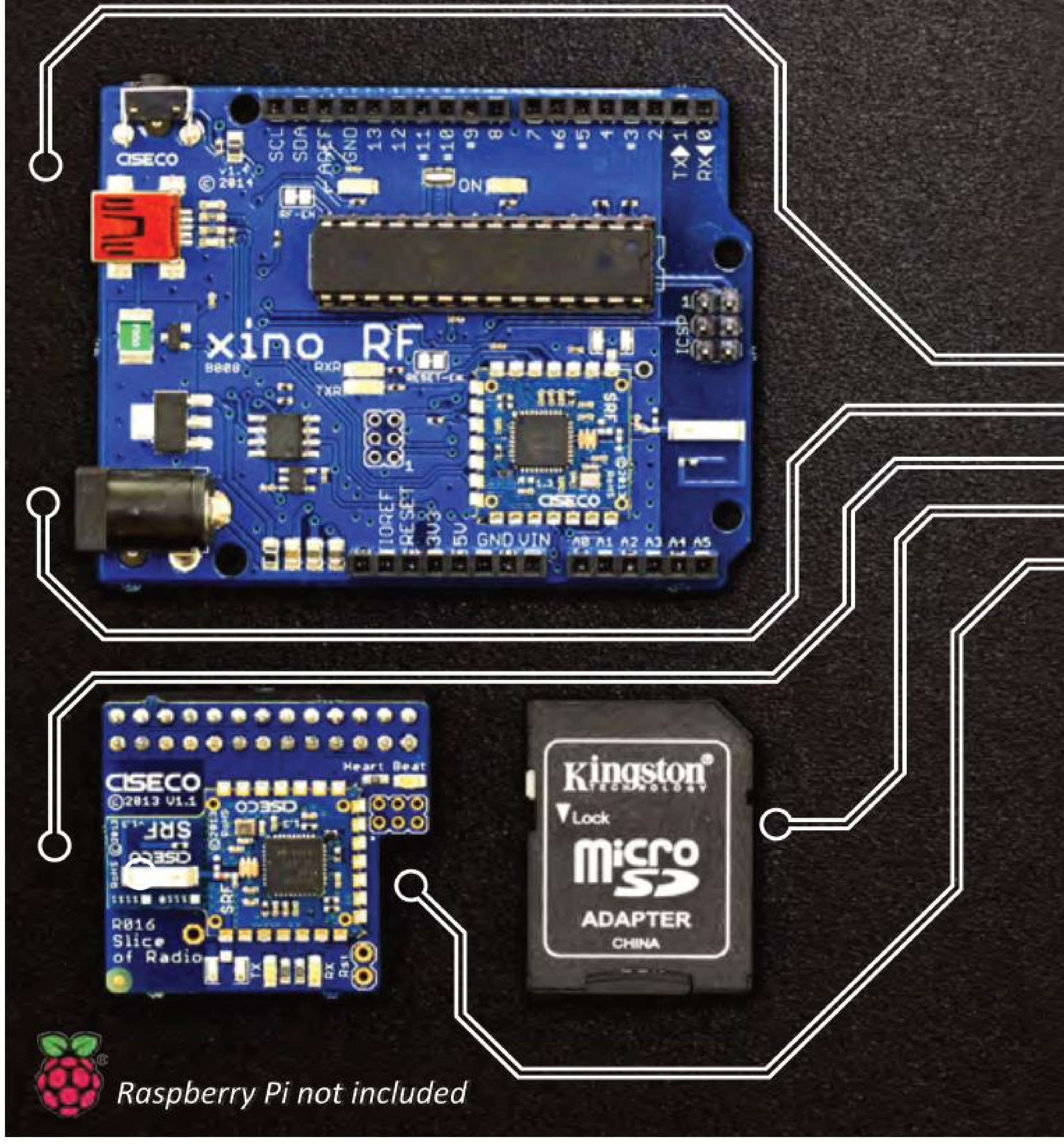

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Teach-In 2014 Update Raspberry Pi B+

by Mike and Richard Tooley

EPE's resident Raspberry Pi expert, Mike Tooley, takes a look at the recently introduced Raspberry Pi Model B+, which aims to put right many of the shortcomings of its predecessor, the Raspberry Pi Model B. So, is this really something to shout about or is it just more of the same? Read on to find out.

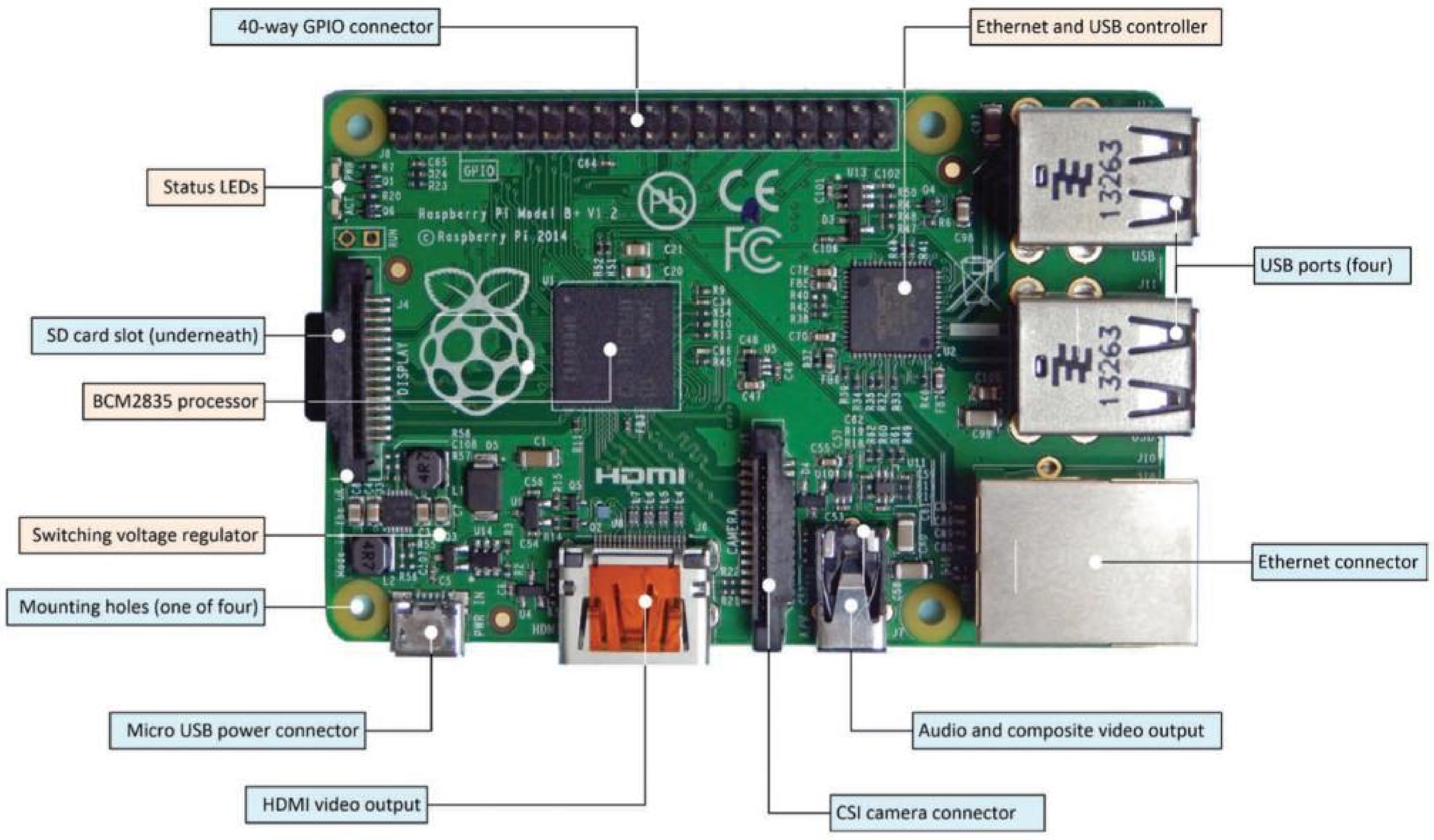

40-way GPIO connector
Ethernet and USB controller
Status LEDs
USB ports (four)
SD card slot (underneath)
BCM2835 processor
Switching voltage regulator
Ethernet connector
Mounting holes (one of four)
Micro USB power connector
Audio and composite video output
HDMI video output
CSI camera connector

Fig.1. Layout of the Raspberry Pi B+

Background

Launched in 2011 and with sales now in excess of three million, there can be little doubt that Raspberry Pi has been a huge success. Not only that, but it has also achieved its original aim of delivering a powerful but low-cost system on which a new generation of enthusiasts can practise their programming skills. And, as many of our regular *EPE* readers have found, what was intended primarily as a learning tool also makes an excellent platform for developing hardware-based projects.

The idea behind a tiny and affordable computer for use in schools and colleges came in 2006, when Eben Upton, Rob Mullins, Jack Lang and Alan Mycroft, based at the University of Cambridge's Computer Laboratory, became concerned about a progressive decline in the numbers and skill level of students applying for undergraduate courses in computer science and related disciplines. In the 1980s and early 1990s many young people were able to cut their programming teeth on a variety of accessible computers, such as the 8-bit Sinclair Spectrum, BBC Micro, Commodore VIC-20 and C-64 machines, and the 16-bit Atari ST and Commodore Amiga computers. However, following changes in the curriculum, the impetus for learning code-style programming in BASIC, C, Pascal and processor-specific assembly language became very much secondary to the need for young people to become familiar with database and spreadsheet applications. The upshot of this was that a generation of young people were largely denied the ability to get to grips with in-depth practical programming skills at school and college. The Raspberry Pi Foundation (a registered educational charity based in the UK) sought to put this right with the laudable aim of advancing the education of adults and children, particularly in the field of computers, computer science and related subjects.

In our most recent *Teach-In* series, *EPE* demonstrated just how handy the Raspberry Pi can be as a general-purpose microcontroller. With network and Internet connectivity, USB ports and support for a high-quality graphical display, the Pi offers a sleek, modern platform on which to do useful development work and, while the Raspberry Pi has somewhat limited I/O capability (no ADC or DAC) we showed how it can be easily augmented with simple software and low-cost hardware for use in a wide range of measurement and control applications.

Changes

There have been so many changes in this latest version of the Raspberry Pi that it might have been better to call it a Model C rather than a Model B+. However, this might also suggest that the Model B+ is actually, with hindsight, what the Model

Teach-In 2014 Update

Readers should note that while this article can be read as a standalone piece, it is best appreciated when read in conjunction with *EPE's Teach-In 2014* series on the Raspberry Pi, which appeared in *EPE* from October 2013 to July 2014.

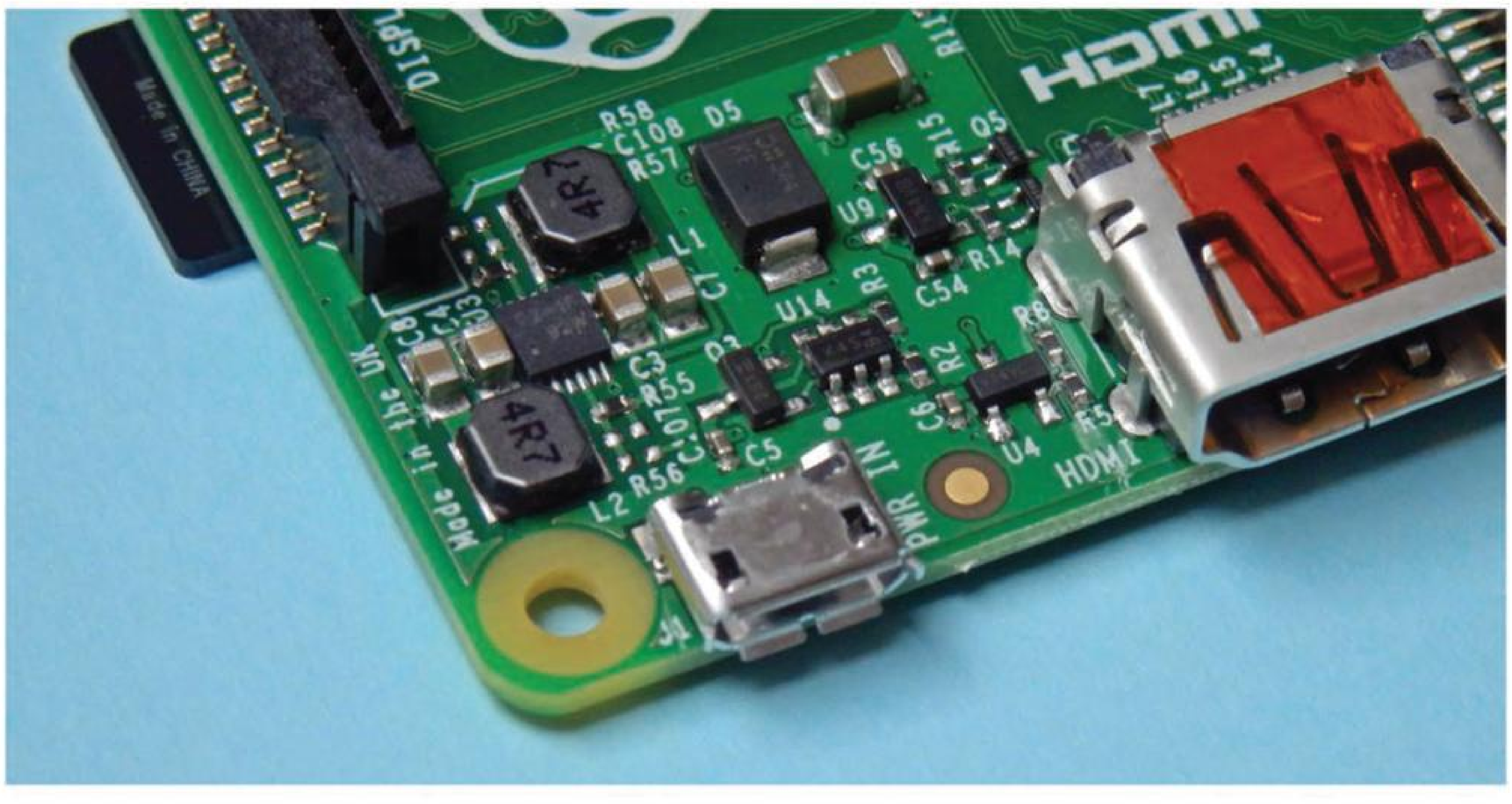


Fig.2. The B+ uses a more efficient switched-mode voltage regulator

Raspberry Pi Model B+ specification

Processor	Broadcom BCM2835 SOC (system on chip)
Core architecture	ARM11
CPU	700MHz low power applications processor
GPU	Dual core multimedia co-processor providing Open GL ES 2.0, hardware-accelerated Open-VG, and 1080 pixel H.264 high-profile decoding (capable of 1Gpixel/s or 24GFLOPs with texture filtering and DMA infrastructure)
Memory	512MB SDRAM
Operating system	Linux (eg, Debian, Raspbian) booting from a Micro SD card
Video output	HDMI (rev. 1.3 and 1.4) and composite PAL/NTSC
Audio output	3.5 mm jack, HDMI
Network	Ethernet 10/100 Base-T Ethernet socket
USB I/O	Four standard USB 2.0 ports
GPIO	40-pin 2.54mm (100mil) expansion header providing access to 27 GPIO signals as well as +3.3V and +5V regulated supplies
Display	Serial display interface (DSI)
Camera	15-pin serial camera interface (CSI-2)
Dimensions	85 × 56 × 17mm
Power	+5V at 2A max via a Micro USB connector

B should have been! In any event, it's good to see that so many of the niggles and shortcomings of the earlier models have now been put right. Here are the most significant changes.

Physical layout

From a quick visual inspection you will find a number of changes to the layout of the Raspberry Pi's printed circuit board. The GPIO connector now has 40 pins (more of this later) and there are now four USB ports neatly arranged in line with the board's Ethernet LAN connector. The HDMI connector has been moved into the area previously occupied by some of the Pi's power supply circuitry and the rather ugly phono connector for composite video has been removed from the board (the composite video signal now appears on an extra (fourth) pole of the 3.5mm miniature jack connector.

The status LEDs have moved to a new position on the board while the network LEDs have moved to the Ethernet connector. The functions of the LEDs have now been consolidated into ACT (activity) and PWR (power). Note that the former only serves to indicate SD card accesses.

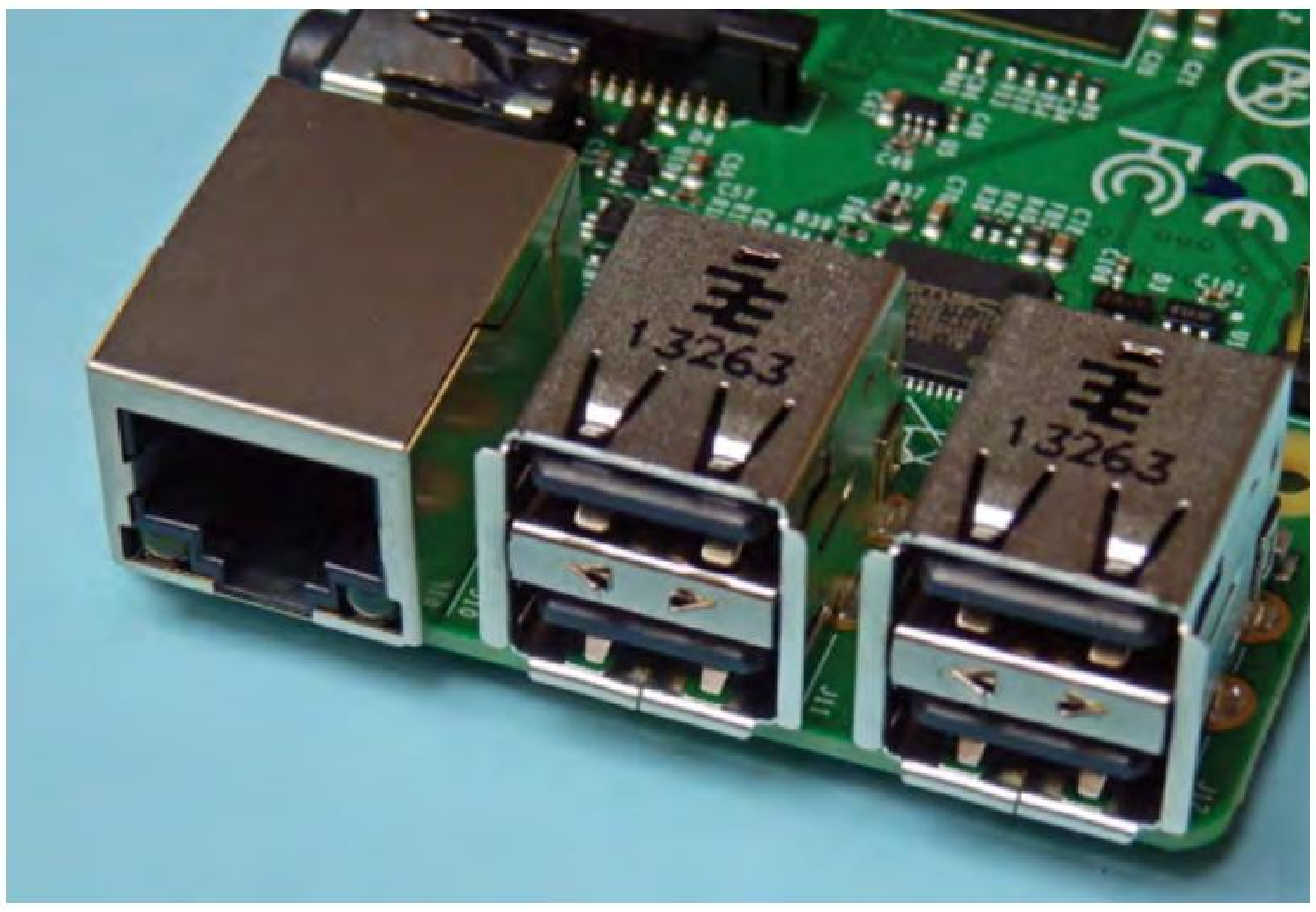


Fig.3. The four USB ports provide a welcome increase in I/O capability

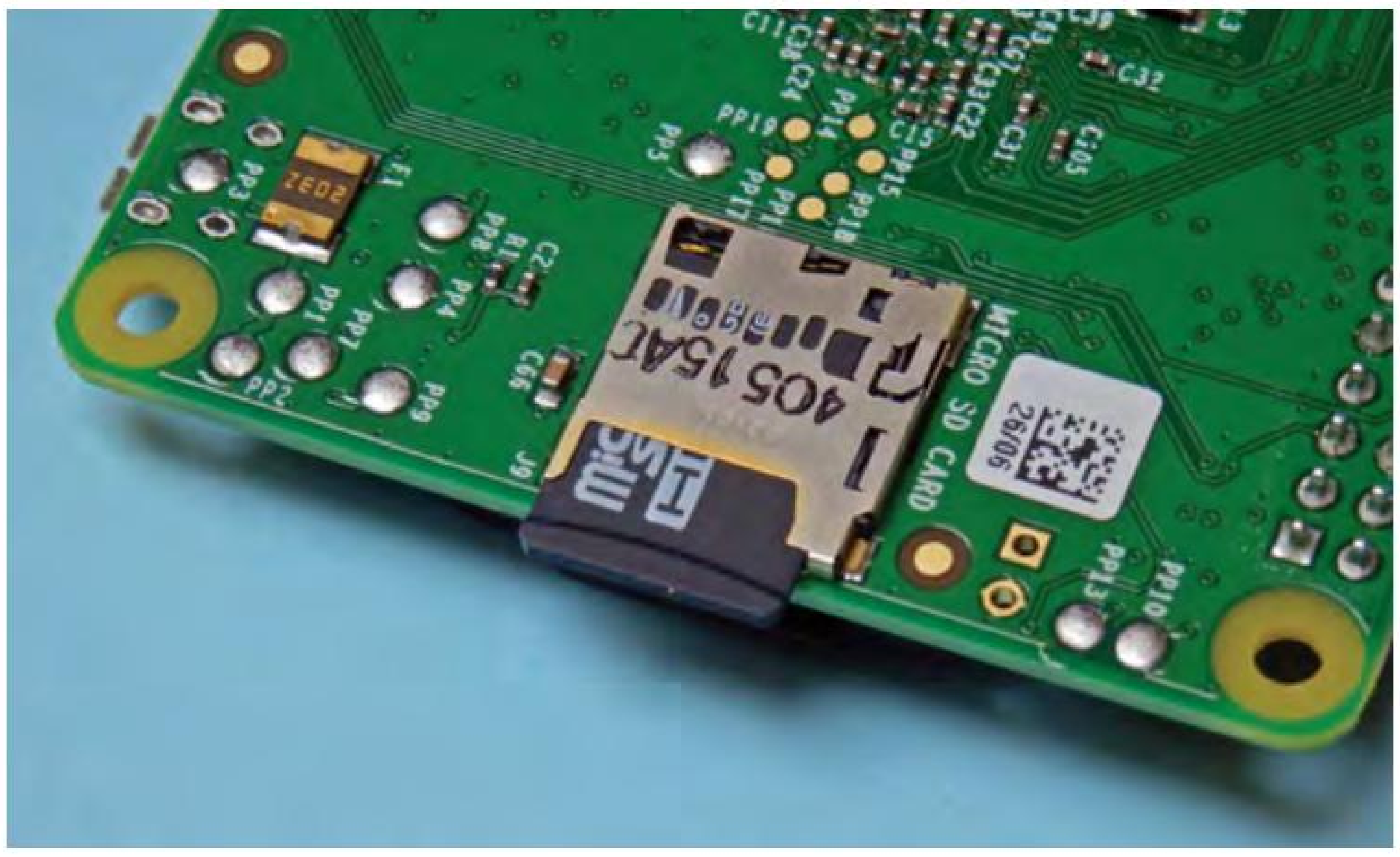


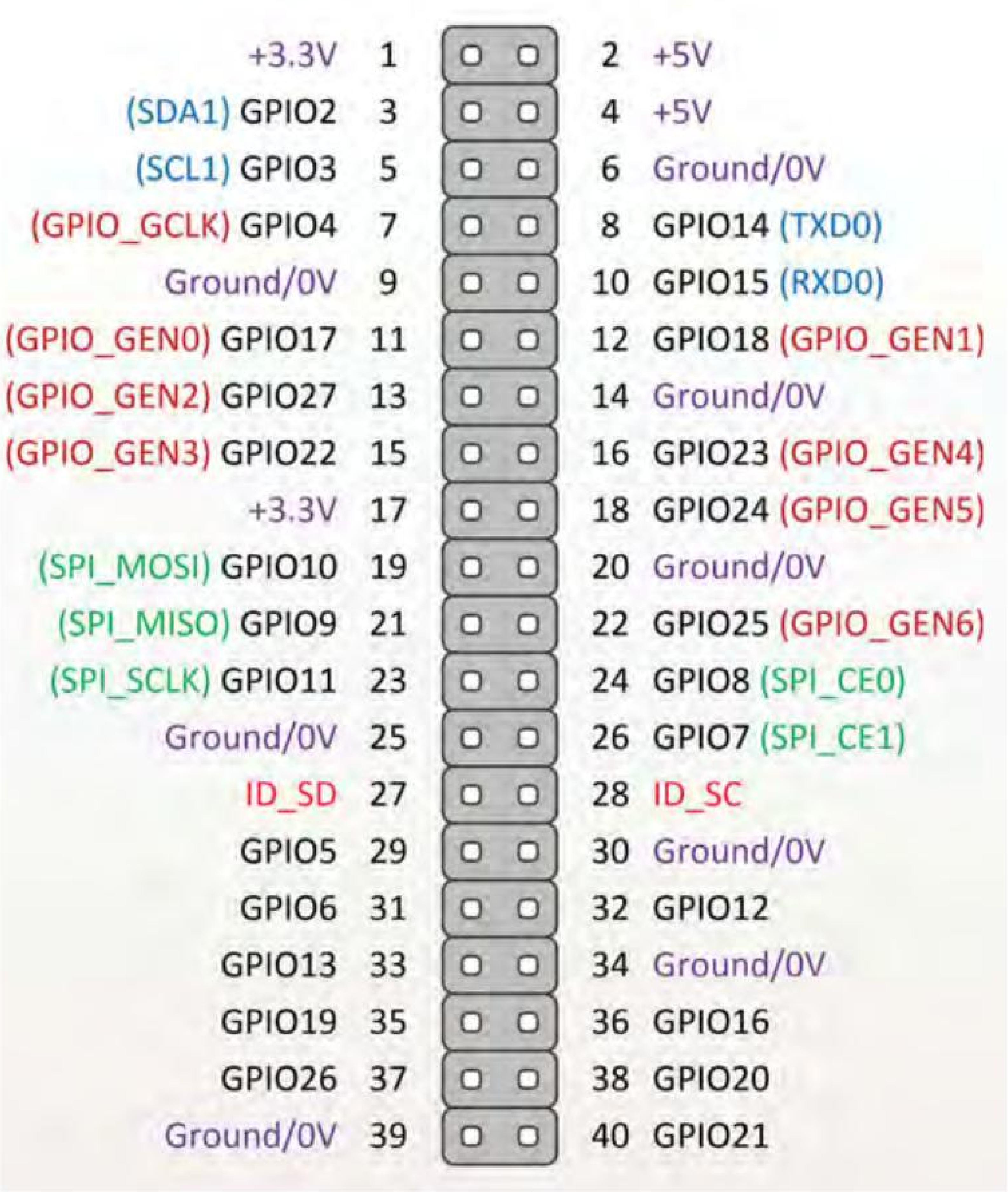
Fig.4. The Micro SD card makes the B+ much neater and avoids the dangers previously associated with the earlier model's projecting SD card

The P2 and P5 GPIO connector pads have also disappeared (see later). On the reverse side of the board the SD card slot has been replaced by a more compact Micro SD slot.

A notable improvement is the inclusion of four mounting holes (missing from the earlier boards) and rounded corners to the PCB. The four mounting holes are drilled to 2.9mm to accommodate M2.5 mounting screws. As always, care should be taken when mounting the PCB on a conducting surface or in an enclosure. In particular, it is essential to ensure clearance below the PCB and to avoid contact with components and traces.

Power supply

The Raspberry Pi Model B has earned something of a reputation for being 'power hungry' and a power unit rated at a minimum of 1A or an externally powered active USB hub, soon becomes essential if you intend to connect the full gamut of external devices (such as keyboards, mice, and Wi-Fi adapters). The B+ goes a long way to putting this right by replacing the original linear voltage regulator with a more efficient switched-mode circuit (see Fig.2). However, with four USB ports on offer you might be tempted to connect devices to each of them and, since you then won't be using an externally powered hub, you might still feel the need for a fairly powerful 5V supply.



+3.3V	1	2	+5V
(SDA1) GPIO2	3	4	+5V
(SCL1) GPIO3	5	6	Ground/0V
(GPIO_GCLK) GPIO4	7	8	GPIO14 (TXD0)
Ground/0V	9	10	GPIO15 (RXD0)
(GPIO_GEN0) GPIO17	11	12	GPIO18 (GPIO_GEN1)
(GPIO_GEN2) GPIO27	13	14	Ground/0V
(GPIO_GEN3) GPIO22	15	16	GPIO23 (GPIO_GEN4)
+3.3V	17	18	GPIO24 (GPIO_GEN5)
(SPI_MOSI) GPIO10	19	20	Ground/0V
(SPI_MISO) GPIO9	21	22	GPIO25 (GPIO_GEN6)
(SPI_SCLK) GPIO11	23	24	GPIO8 (SPI_CE0)
Ground/0V	25	26	GPIO7 (SPI_CE1)
ID_SD	27	28	ID_SC
GPIO5	29	30	Ground/0V
GPIO6	31	32	GPIO12
GPIO13	33	34	Ground/0V
GPIO19	35	36	GPIO16
GPIO26	37	38	GPIO20
Ground/0V	39	40	GPIO21

Fig.5. Pin assignment for new 40-pin B+ GPIO connector

Table 1: Raspberry Pi comparison chart

	Model A	Model B	Model B+
System on-chip	Broadcom BCM2835	Broadcom BCM2835	Broadcom BCM2835
CPU	700MHz low power ARM1176JZ-F applications processor	700MHz low power ARM1176JZ-F applications processor	700MHz low power ARM1176JZ-F applications processor
GPU	Dual core VideoCore IV multimedia co-processor	Dual core VideoCore IV multimedia co-processor	Dual core VideoCore IV multimedia co-processor
RAM	256MB SDRAM at 400MHz	512MB SDRAM at 400MHz	512MB SDRAM at 400MHz
Storage	SD card	SD card	MicroSD card
USB port(s)	1 × USB 2.0 port	2 × USB 2.0 ports	4 × USB 2.0 ports
Ethernet	None	1 × 10/100Mb Ethernet via a standard RJ45 connector	1 × 10/100Mb Ethernet via a standard RJ45 connector
LAN/USB controller	BCM2835 (USB only)	SMSC LAN9512-JZX (Ethernet LAN/USB)	SMSC LAN9514-JZX (Ethernet LAN/USB)
Video	HDMI, Composite RCA	HDMI, Composite RCA	HDMI, composite RCA (available from the 3.5mm jack connector)
Supported video resolutions	640 × 350 to 1920 × 1200, incl 1080p, PAL and NTSC standards	640 × 350 to 1920 × 1200, incl 1080p, PAL and NTSC standards	640 × 350 to 1920 × 1200, incl 1080p, PAL and NTSC standards
Audio	Multi-channel HD audio over HDMI; stereo from a 3.5 mm miniature jack connector	Multi-channel HD audio over HDMI; stereo from a 3.5mm miniature jack connector	Multi-channel HD audio over HDMI; stereo from a 3.5mm miniature jack connector
Operating systems	Raspbian, RaspBMC, Arch Linux, Risc OS, OpenELEC, Pidora, etc.	Raspbian, RaspBMC, Arch Linux, Risc OS, OpenELEC, Pidora etc.	Raspbian, RaspBMC, Arch Linux, Risc OS, OpenELEC, Pidora, etc.
Power supply	+5V at 600mA nominal, 1.2A max.	+5V at 750mA nominal, 1.2A max.	+5V at 600mA nominal, 1.8A max.
GPIO	26 pins	26 pins	40 pins
Camera and display I/O	CSI-2 for Raspberry Pi camera modules; DSI for Raspberry Pi displays	CSI-2 for Raspberry Pi camera modules; DSI for Raspberry Pi displays	CSI-2 for Raspberry Pi camera modules; DSI for Raspberry Pi displays
Power connector	Micro-USB	Micro-USB	Micro-USB

SD card

Earlier versions of the Raspberry Pi made use of a standard SD card for storing the operating system, programs and data. These cards were slotted into a rather flimsy connector on the underside of the Pi's printed circuit board and this arrangement was far from perfect as the card projected a long way from the board edge and was thus somewhat prone to flexing. This problem has been put right on the B+ by using a Micro SD card (see Fig.4). This card is very much smaller than a standard SD card, so the the Micro SD card reader sits reasonably flush with the printed circuit board and so it is much less likely to be disturbed during operation or while the Pi is in transit. Micro SD cards can also be fitted into low-cost adapters and this allows them to be used in earlier versions of the Pi, as well as being transferred to a desktop or laptop computer for backup and copying.

I^2C EEPROM identification

Pins 27 and 28 of the B+'s GPIO connector allow the Pi to automatically identify an EEPROM present on an external I^2C interface. At boot time, the I^2C interface will look for an externally connected EEPROM that identifies the attached board, permitting automatic set up of the GPIO and, optionally, the required Linux drivers. These two GPIO pins (27 and 28) are designed solely for the identification function and they should be left unconnected when the automatic EEPROM identification function is not required.

The GPIO connector

As well as I^2C EEPROM identification (see earlier) the new 40-pin GPIO connector adds nine additional GPIO signals that were earlier present on the unpopulated P2 and P5 headers. If you need to produce GPIO code that will work across all versions of the Pi you should either avoid using the I^2C EEPROM identification feature or include a routine in your code (during initialisation) that checks the board version and assigns the GPIO pins according to the result.

With the Model B+ the P2 and P5 headers have been removed and their signals made available on the 40-way GPIO connector. The additional signals available from the 40-pin connector (P1) are as follows:

GPIO5 and GPIO6
GPIO12 and GPIO13
GPIO16 and GPIO19
GPIO20, GPIO21 and GPIO26.

The new GPIO connector makes it possible to use standard 40-pin IDE cables of the type used to connect multiple hard drives to a PC motherboard. Since these cables usually have two hard drive connectors it is possible to connect several interface cards at the same time using a simple 'GPIO bus' arrangement. The pin assignment for the new 40-pin GPIO connector is shown in Fig.5.

Summary

Priced at around £25 (less VAT and delivery) the Raspberry Pi Model B+ represents amazing value. The new features go a long way towards addressing the shortcomings of the Model B and the additional I/O capability, in particular, is a very welcome addition.

NET WORK

by Alan Winstanley

Torque like a Pro

WELCOME to the January 2015 edition of *Net Work*, the column specially written for Internet users. I start this month's *Net Work* with a warm 'thank you' to those readers who kindly contacted me following our 50th Birthday celebratory features in the November and December issues. I was delighted to receive your comments and reminiscences, and I hope the feature also helped our current and new-generation readers to see how our magazine has evolved over time, and maybe show what being an electronics hobbyist was like in post-war Britain, when life without the Internet, web and email was very different. There were still a lot of exciting discoveries to make in the world of hobby electronics.

On-board diagnostics

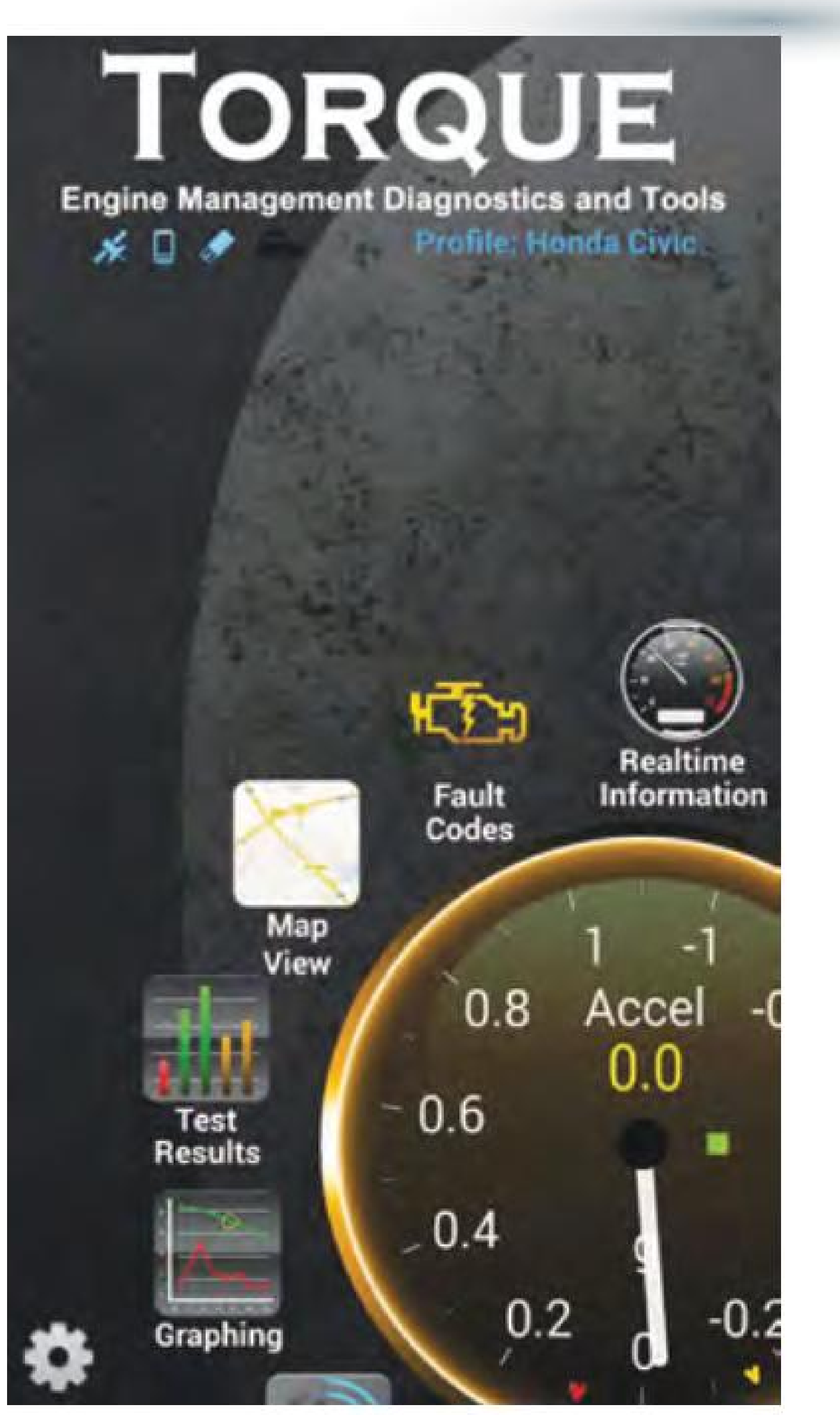
This month's *Net Work* could not be in sharper contrast to the kind of cosy kitchen-table construction we depicted half a century ago. The very interesting *GPS Tracker* project in November 2014's issue is a self-contained project with its own GPS module and SD memory card that allows car journeys to be mapped onto Google Earth. It piqued my interest, because I had recently tried a cheap and cheerful OBD II (on-board diagnostics) transmitter that hooks onto the diagnostic socket of most cars manufactured in the last 10-15 years. The Bluetooth module sends the car's diagnostic data to a compatible logging device, such as an engine analyser or (as in my case) an Android smartphone, which raises the prospect of enhancing the captured data by means of an Internet connection. The module's low price on eBay meant it would be no loss if it did not work, so I decided to try one. How would this temptingly cheap and cheerful gadget work in practice – if at all?

A compatible Bluetooth OBD II transmitter fitted to the author's car. This one has a very handy on-off button

My OBD II transmitter arrived in the shape of a small ELM327-based unit that slotted onto my car's diagnostic socket, which is located within easy reach of the steering column (see photo): the module was a little wobbly and not the snuggest fit, but it connected to the car perfectly well. (Details of the OBD chipset are available at: **http://elmelectronics.com/obdic.html#ELM327**) Unlike other similar adaptors, mine had a convenient on/off button to disable it when not required. (This would prove useful during early testing!)

The business end of the system was housed on my HTC One smartphone, where I seamlessly installed the excellent *Torque Pro* vehicle diagnostics app for Android via the Google Store, though the developer's website at **http://torque-bhp.com** is not so informative. The total cost of adaptor and app was just over £10 (~$15). Unfortunately, *Torque Pro* does not support Apple's iOS, but PC software was included with my adaptor if I wanted to try using a Bluetooth-enabled Windows laptop instead. Do remember to confirm that your devices' Bluetooth versions are compatible with each other: they probably will be, but my old TomTom GO Bluetooth, for example, cannot pair with my HTC One although the ELM-based car module paired with the phone easily.

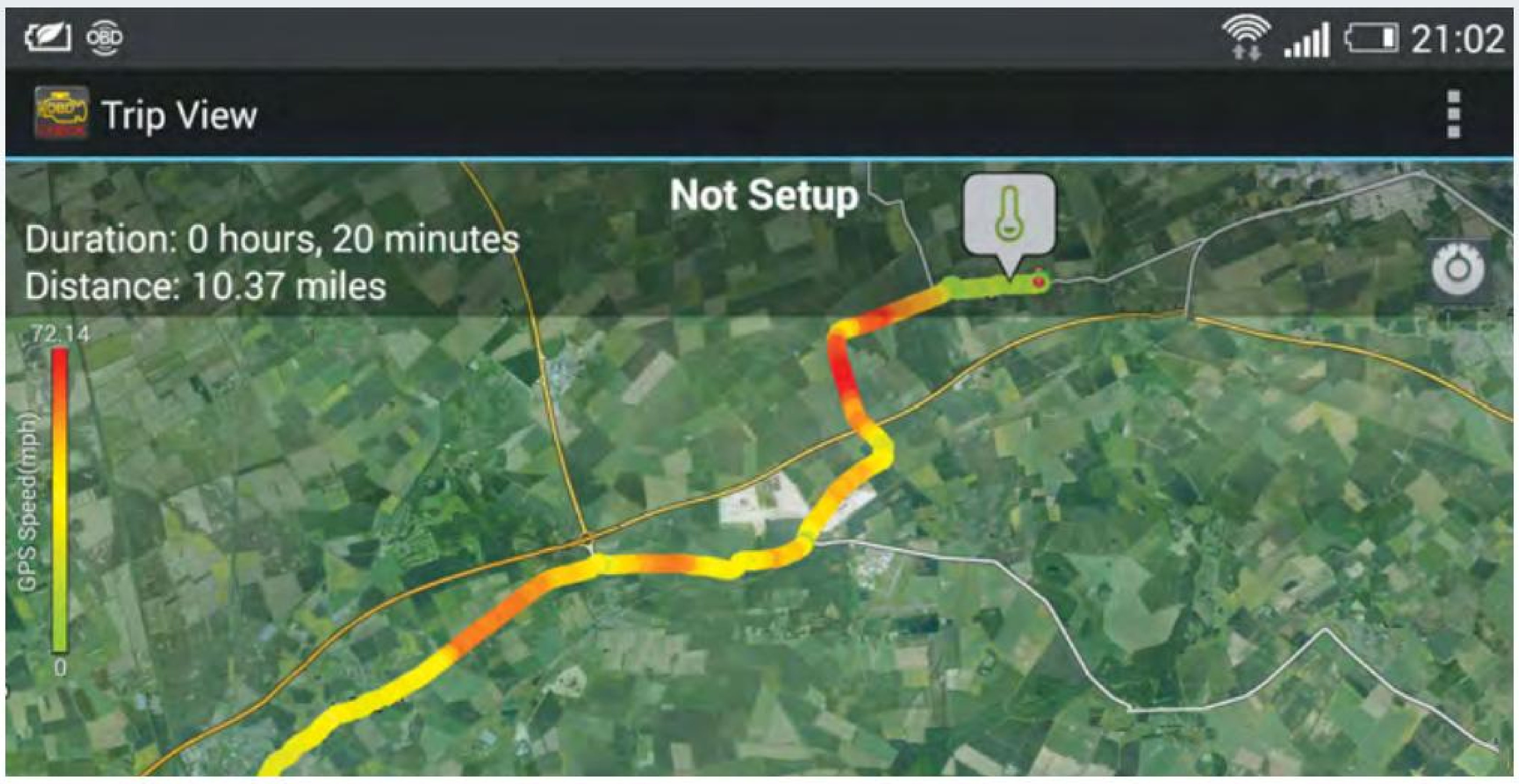
This budget-priced vehicle-logging set-up has many tricks and surprises up its sleeve. First of all, if your phone is GPS-enabled then vehicle journey data can be displayed directly on the phone after completion, superimposed either on Google's satellite images or on a basic street map. Otherwise an external GPS adaptor can be used with *Torque Pro*. Travel data can be exported as a .kml file for importing into Google Earth on a PC (simply drag and drop the .kml file onto Google Earth). In a test sample, journey data was accurately displayed but the effect was a staccato sequence of green arrows with velocity shown adjacent.



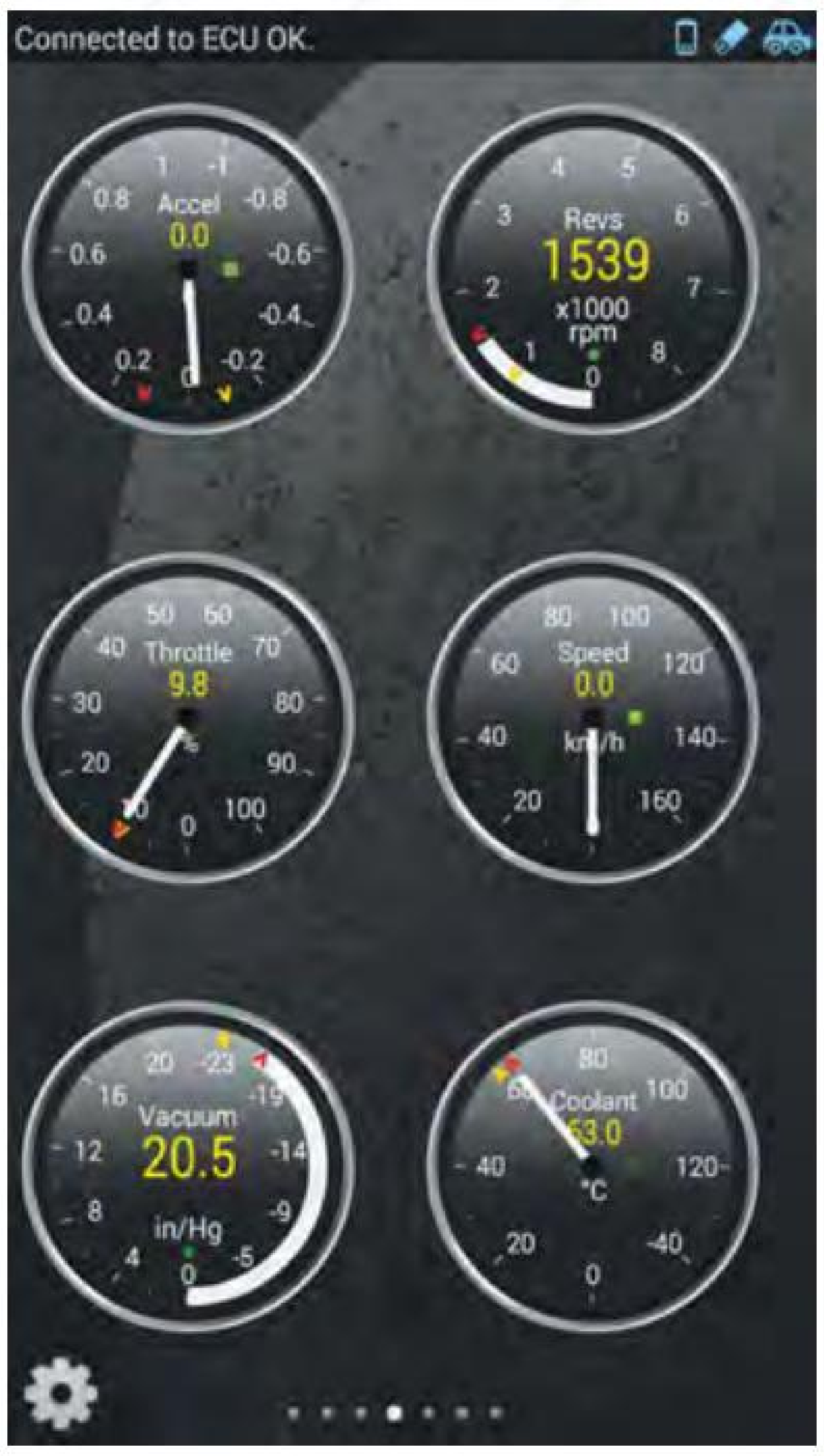
Torque Pro app for Android reads data from a vehicle's OBD II port and captures journey data using GPS

Dials and miles

Once it was enabled and paired to my phone, *Torque Pro* captured GPS location, vehicle speed as well as approximate (GPS) altitude and my efforts to display journeys on the smartphone were very successful. The route is depicted with a colour scale on a Google map which can be pinched and zoomed in the normal way. *Torque Pro* logs the maximum speed as a red line and slower speeds as a green or yellow one. It was easy to choose a journey stored on the phone and display data in Trip View, showing high speed bursts on dual carriageways, or slow speeds when picking my way through villages. It had near pin-point accuracy too, as it



A Trip View of the logged journey displayed on the smartphone. Speed scale is on the left. Note the temperature icon when the car reached operating temperature



The dashboard can display many different parameters in various styles of gauge. A reverse HUD display is also available

showed a three-point turn in a city car park (and the very spot that I parked). The return journey was also shown, with a line on the map clearly showing my homeward progress on the other side of the road.

Further options include analysing the phone's accelerometer readings, and the map displayed X, Y or Z-axis g-force as I cornered, braked or accelerated (the phone's accelerometer can be calibrated separately). Generally, the map logging worked seamlessly once it had been paired and set up (a one-off process), and I found that simply by turning on the phone's BT and GPS, then pressing the 'on' button on the OBD sender, the system started working effortlessly and journeys were saved to the phone without any problem. It is probably best to turn off or remove the transmitter if it is not being used for longer periods.

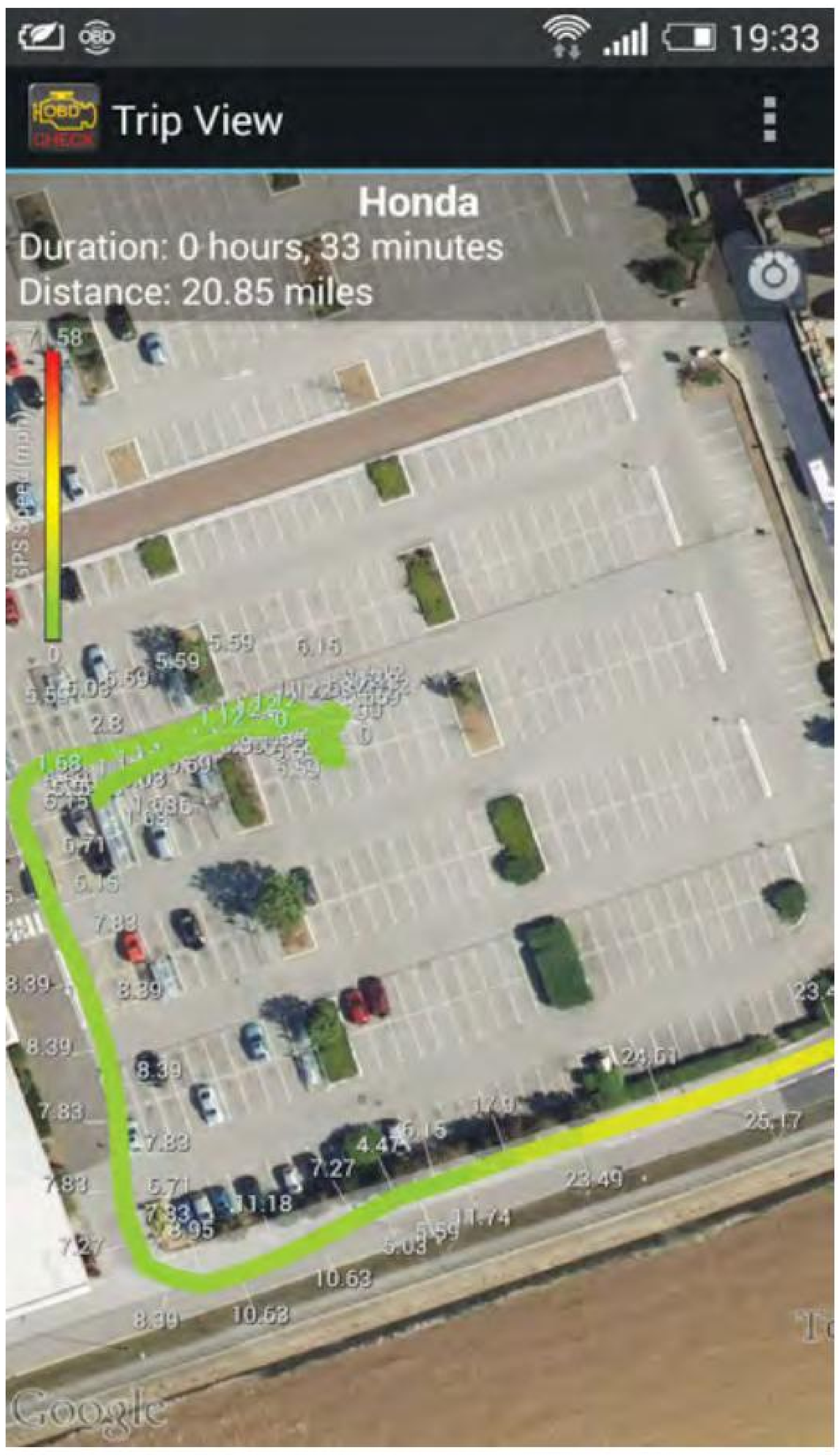
GPS interaction with Google Maps is one aspect, but another valuable feature is the vehicle's OBD data captured by *Torque Pro*, and here things got really interesting. *Torque Pro* can display real-time data on a choice of on-screen dials on your Android phone or tablet, such as bargraphs or traditional-style displays. You can create a digital dashboard using your choice of widgets; for example, RPM, speed, vacuum, water coolant temperature, throttle, boost and many more parameters are accessible and you can choose units of measurement and styles of dial to suit your taste. As speed is also measured, various performance parameters including best 0-60 or ¼-mile time can be checked, if your vehicle system is able to provide raw data.

Torque Pro goes further by offering to generate alarms for specific vehicle events, with a list as long as your arm, depending on how many sensors are available on your car. As a basic test I enabled the coolant temperature alarm and sure enough, within a few minutes of setting off, a spoken (English) voice told me that the operating temperature has been reached. Air inlet temperature was also measured and an alarm could be set, and the smartphone can warn if you are driving too aggressively before the engine has warmed up properly. This data was again captured successfully and Google Maps displayed a temperature flag icon once my car had warmed up. (However, trying the CO2 Instantaneous Level alarm was a mistake, as I couldn't silence the nagging alarm! At that point I reached under and turned off the transmitter.) Car enthusiasts will definitely want to experiment, and an extremely wide choice of parameters is available for analysis, although your car might not be able to offer all of them.

Last but not least, there is always the prospect of using the OBD socket as the car manufacturer intended: for reading the vehicle's ECU error codes, and *Torque Pro* will scan and clear them as a separate function. A friend's new Mitsubishi Shogun 4×4 had a nasty habit of going into limp-home mode while towing a caravan, and the dealer charged £70 just to reset it without ever curing the problem; an app like *Torque Pro* could help owners to obtain the fault code for themselves and then Google for advice from fellow motorists. (They gave up and sold the car.) The app can also quick-scan the ECU in real time if desired.

As befits today's socially-networked society, the app can transmit travel data via a smartphone to Twitter and Facebook so that you can share your trip with friends and family – mobile data connection permitting. The flipside is that your smartphone's battery will take quite a pummelling with so many services up and running. There is further support in *Torque Pro* for customising gauges and using plug-ins, including a racing-car-style display, which looks like fun. A head-up display (HUD) mode is also on the menu, the phone's inverted screen reflecting into the car's windscreen if a suitable holder is used – try eBay. An adjustable holder that clips the phone onto the car's air vents might be a way of displaying it on the dashboard, and again, eBay is the place to try first.

Torque Pro is typical of low-cost specialist apps that are labours of love for their developers, often individuals who work enthusiastically to share useful programs at a very low cost. Thanks to the excellent *Torque Pro* app there is plenty to keep the automotive enthusiast happy for hours; and couple it with a simple ELM-based Bluetooth module and you have plenty of fun ahead of you over the Christmas holidays. The module is available from eBay for such a low price that it's worth the slight gamble of incompatibility; let me know how you get on!



Torque Pro app for Android reads data from a vehicle's OBD II port and captures journey data using GPS

Seventh heaven

If readers are shopping around for a new PC or Windows laptop this winter, it's very likely that Windows 8.1 will be the operating system that stores want you to buy, whether customers like it or not. Although the Windows XP desktop is historically dead in the water – but still used by UK institutions – as a visit to my GP showed – the curtains are now coming down on sales of Windows 7 computers too. If you want a Windows 7 machine then it's time to act, because stocks of Windows 7 disks (especially versions targeted at home users) will soon dry up, with only Windows 7 Professional remaining on sale for PC assemblers. Some mail order PC suppliers claim to have bought up sufficient stocks of W7 licences in advance, but if you like to assemble your own PC – as I do – then W7 Professional is probably the version to chose.

Opinions about Windows 8.1 are still divided. I know of hardened PC sellers who rave about it, but personally I simply hate the style of awkward, flat, two-dimensional meaningless 'tiles' that have tablet and touchscreen users in mind, and I have no desire to buy yet another suite of software to avoid compatibility problems either. So, readers, my choice of OS for my new PC will be Windows 7 Professional and its pretty 3D icons, and hopefully my legacy 32-bit software will run fine on a new 64-bit machine, and I will also enjoy the benefits of USB3.0.

If you have lost some old software disks, or perhaps yearn for some legacy software then one site worth visiting is at: **http://vetusware.com**, which hosts a wide variety of 'abandonware'. Perhaps you are a PC hobbyist or want to re-commission an old computer: you will find old DOS, Windows 3, W95, W98 and OS/2 programs with CD or floppy versions sometimes available, and older XP programs are there too. It may be feasible to run them again on a modern machine using a virtual machine, or you could try Compatibility Mode in Windows 7 instead.

That's all for this month's *Net Work*. You can contact the author at: **alan@epemag.demon.co.uk** and I close by wishing readers everywhere a safe and happy Christmas and a prosperous New Year.

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Practically Speaking

Robert Penfold looks at the Techniques of Actually Doing it!

Labels and overlays

THE previous article in this series covered the production of front-panel legends and complete panel designs using cheap or free software. This month, we move on to the problem of actually getting labels or complete overlays onto a front panel – and getting them to stay there! Although labels and panels produced with the aid of a computer are now probably the norm, there are alternatives that are worthy of consideration.

Low tech

Rub-on transfers, or 'dry' transfers as they are also known, used to be the most popular method of labelling projects. Getting good results takes a certain amount of skill and practice, but it is possible to get some very professional looking results. This type of lettering is not very durable, and in use it tends to rub off almost as easily as it rubs on. Some form of protective coating is therefore needed, such as a coat or two of spray-on lacquer.

The range of transfer lettering available these days is tiny when compared to ten or twenty years ago. Most of the transfers currently on offer are aimed at the craft market, and using them it would be easy to end up with a project that looked more like a greetings card! Some transfers that are suitable for our purposes are still available though, but they can be difficult to find. The range of small lettering transfers is now quite limited, so it is a matter of using what you can get rather than the style and size you would like.

The simple Dymo labellers (Fig.1) used to be popular for making panel legends, but I suppose technology has to some extent overtaken this type of labeller, which is purely mechanical and has no electronics. They have the advantage of being relatively cheap to buy and run. The labels are produced using a simple embossing system that produces quite crude results by modern standards. Results are perfectly readable though, the labels are very durable, and they are very much better than having no panel legends at all.

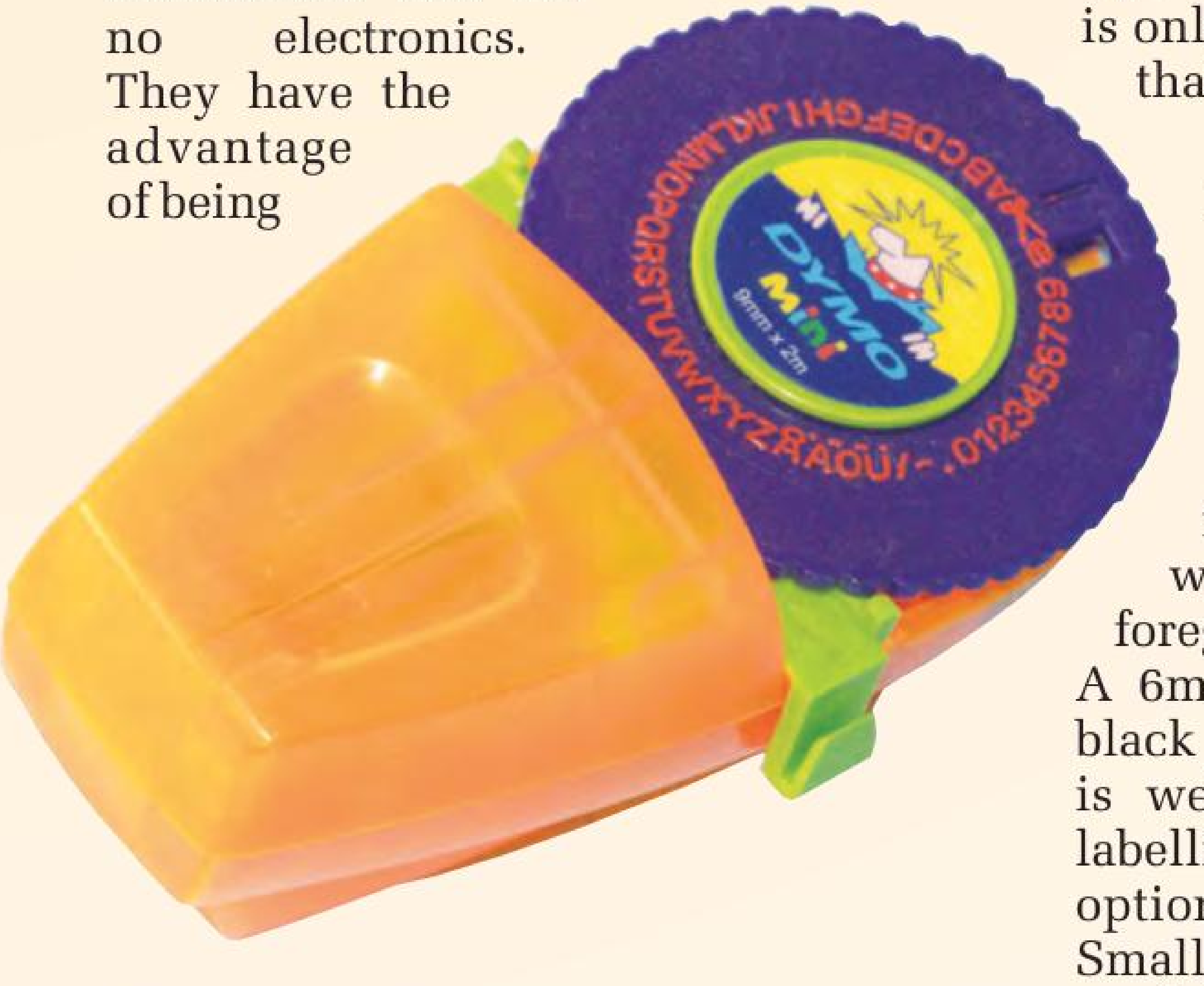


Fig.1. The Dymo labeller is of the 'cheap and cheerful' variety. However, it can quickly produce labels that are very durable

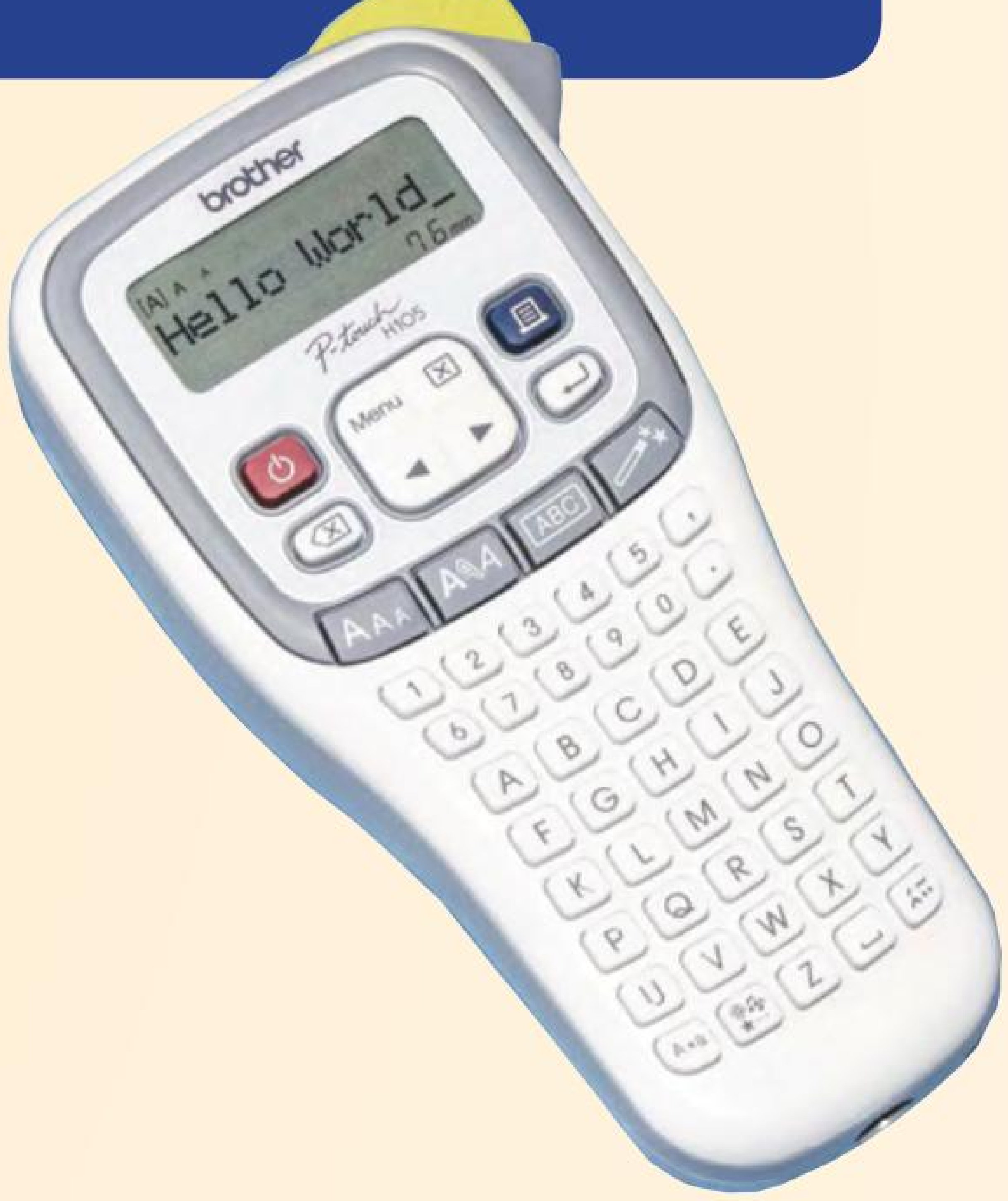


Fig.2. An inexpensive electronic labeller such as this Brother H105 is quite sophisticated. A range of print sizes, styles and effects can be provided, but there is only one font on offer

Got it taped

These days, a small electronic labelling machine (Fig.2) probably offers the best alternative to computer produced labels. These use cartridges that contain self-adhesive tapes. Even the inexpensive types can usually accommodate tapes of three or four different widths. Inexpensive labellers are unlikely to take the wider tape sizes, but in the current context it is only the narrower (3.5-12mm) ones that are needed.

With a modern labeller it is possible to vary the size of lettering, and various styles are also available. Unfortunately, unless you opt for one of the more upmarket labellers there will probably be only one font. The tapes can be obtained with various combinations of foreground and background colour. A 6mm or 9mm tape that produces black lettering on a clear background is well suited to most front panel labelling, but there are many options available if you need them. Small labelling machines are often available on special offers, and can be surprisingly cheap. However, the tape cartridges are not particularly cheap, and could cost more than the labeller.

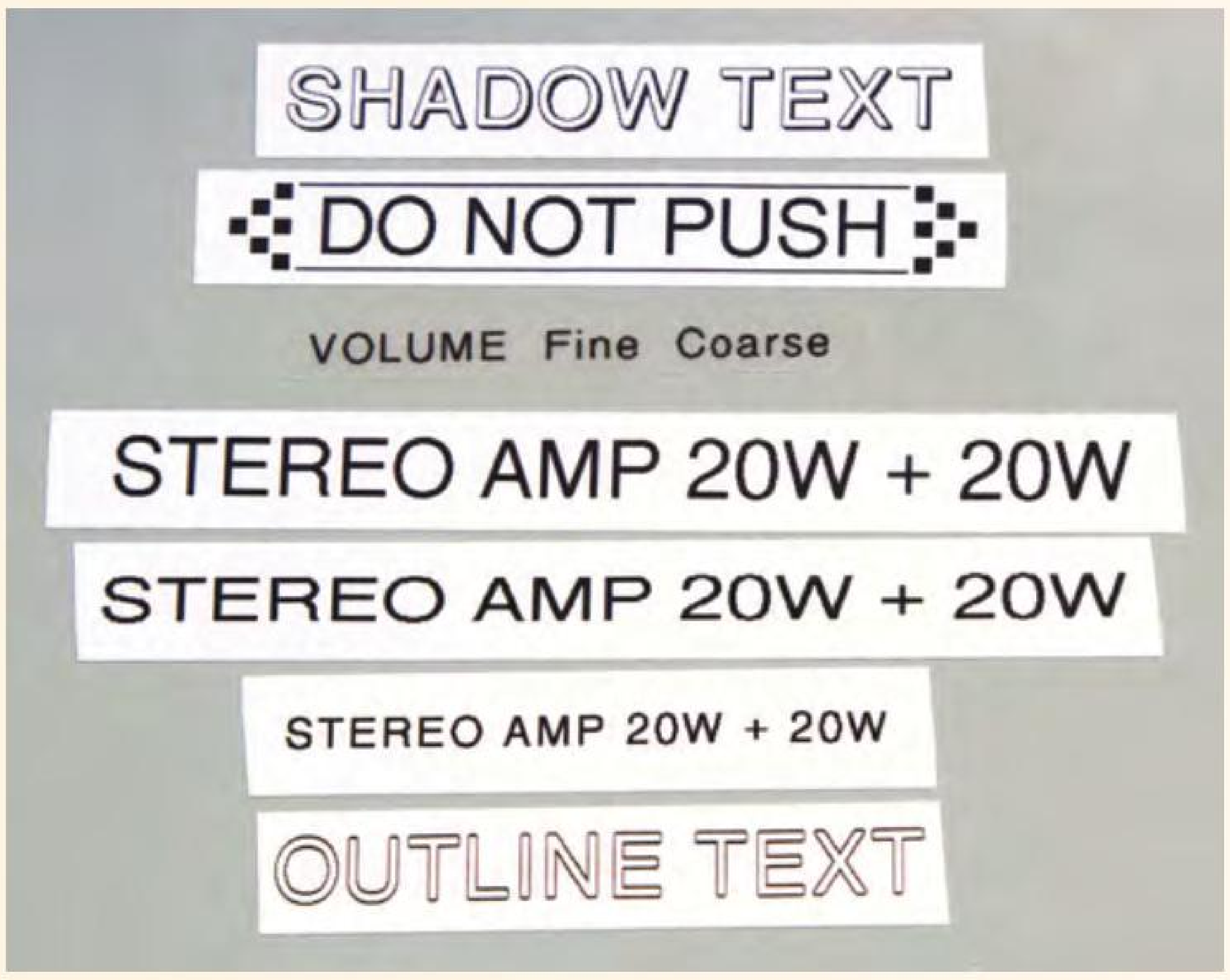


Fig.3. An electronic labeller can provide a range of print sizes, styles, and effects, and only a small selection is shown here. The print quality does not equal that of a modern printer, but it is perfectly adequate

In terms of quality, the results obtained from inexpensive labelling machines are not generally as good as those created by a computer and inkjet or laser printer. The characters are produced using a thermal printing and dot-matrix system, but the resolution is low in comparison to a modern printer. Most of the characters are a bit rough at the edges when examined closely (Fig.3), but this is not particularly noticeable in use. The lettering is certainly very distinct and easy to read.

A labeller provides a quick and easy way of adding legends to a front panel, and the labels produced are very tough. Most of the tapes are of the laminated variety, and the built-in protection provided means the labels produced will normally last for years without the need for any additional coating.

The self-adhesive backing sticks the labels instantly to practically any clean and flat surface, and it seems to be very long lasting. On the downside, this type of adhesive does not permit labels to be slid into place, and even small adjustments are not usually possible once the label has touched the panel. Unless it has been fully pressed down and into place, it is usually possible to carefully peel off a label and try again. This might damage the label, but a replacement can be printed quickly and cheaply.

Hard copy

On the face of it, there are no problems for those who elect to produce labels or complete overlays using a computer and a printer. Any modern inkjet or laser printer will produce high quality results. The problem is in getting good durability, which is something that will probably not be obtained if you simply print out designs onto plain paper, and then stick them in place using whatever adhesive you happen to have available.

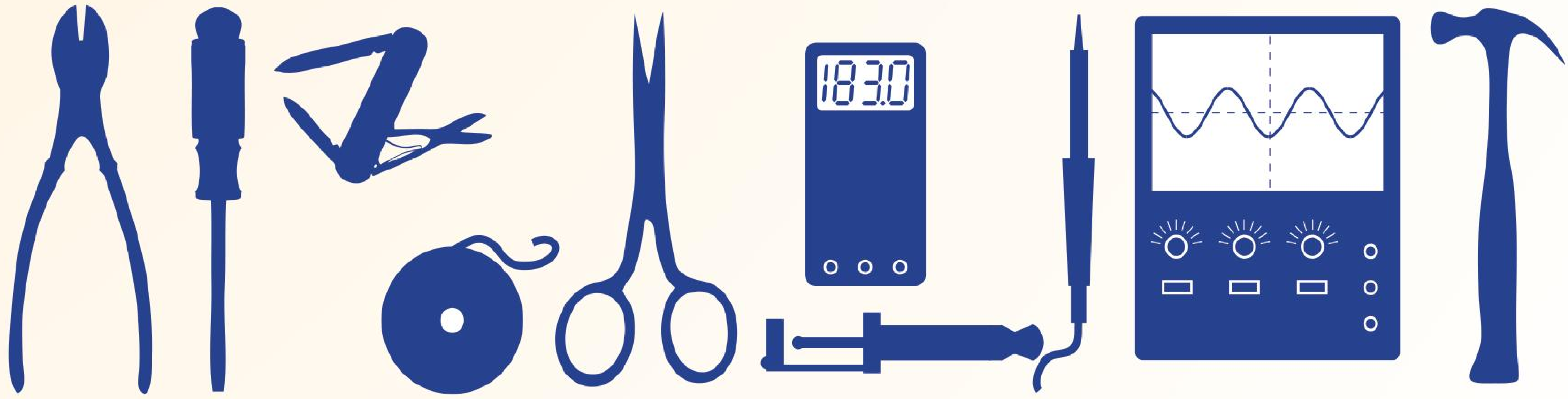
In the current context, a laser printer is preferable to an inkjet type. With a laser printer, the lettering is produced using toner powder and a thermal process that gives relatively tough results. The lettering is also waterproof, which is definitely not the case with inkjet printers. Hard copy from an inkjet printer is vulnerable to smudging and smearing if it gets wet, or even if it becomes damp from condensation.

Ordinary paper is vulnerable to finger marks and general wear unless it is protected by some form of transparent covering. The easy way around this when using a laser printer is to use high quality paper that has a gloss or satin finish. An even better alternative is to use the plastic sheets that are made for use with laser printers. These include transparent plastic sheets that are obviously ideal if you would like to retain the natural colour and finish of the panel. Do not use any plastic media that is not specifically designed for use with laser printers. The heat of the printing process can melt some plastic sheet material, which can leave the printer in an unusable and probably unrepairable state.

Modern inkjet printers can accommodate a wider range of papers than the early types, but are not usable with most types of plastic printing media. With a laser printer, the lettering resides on the surface of the printing media, and it will stick reliably to practically any material that is reasonably clean. The ink droplets from the print head of an inkjet printer need to soak slightly into the surface of the printing media. Most papers have sufficient absorbency to give good results, but with plastic media the ink droplets are not absorbed and tend to merge into tiny puddles. This gives poor print quality, and the dried ink does not adhere to the media and can be wiped off. It is possible to use an inkjet printer with plastic media, but only if it is a type that is specifically designed for use inkjet printers. This type of plastic printing media has a special coating on one side, and this provides the slight absorbency needed by the ink droplets.

In order to get really good results with paper it is important to use one that is specifically designed for this type of printing. This is especially important if the panel design includes artwork or large lettering that could cause ‘bog standard’ paper to absorb so much ink that it becomes distorted. This is known as ‘cockling’ and it can make it impossible to get the overlay to fit flat against the panel. Fairly thick paper that is designed specifically for use with inkjet printers is likely to provide the best looking and longest lasting results. In fact, it is probably worth paying the extra cost of a good quality inkjet photo paper.

Using a heavy gauge of paper minimises problems when gluing the overlay in place. A problem with something like ordinary 80gsm copier paper is that it is quite thin and absorbent, which can give problems with adhesive applied to the reverse side of the paper producing blotchy stains on the front side. Any craft shop or large stationers should be able to supply adhesive sprays that are specifically designed for applications such as this. Using one of these minimises the risk of the adhesive soaking through the paper, but it



is still advisable to use it sparingly. Adhesives of this type usually enable the overlay to be repeatedly removed and repositioned, so that it is not necessary to get it precisely in place at the first attempt.

A simple alternative is to cover the panel with a layer of double-sided adhesive tape, and then add the overlay onto this. There is no risk of the adhesive soaking through the paper as it is not in a liquid form. It is possible to do a certain amount of peeling and repositioning if the overlay is made from some sort of plastic material, but if it is made from paper it is essential to get it right first time. Another alternative is to use self-adhesive media, but this approach is relatively costly, and if you can actually track down something that meets your requirements then do use it.

Media coverage

Some labels and overlays are inherently tough, but this is not the case with hard copy produced using an inkjet printer. A transparent covering of some sort is needed in order to give the panel a finish that will stand the test of time. A laser printer produces reasonably durable results, but some form of transparent covering will still give a worthwhile improvement.

The simplest method is to use a transparent lacquer or varnish, but there is a potential problem when using this method with an overlay produced using an inkjet printer. Even if it has fully dried, the ink is soluble in water and most other liquids. It will almost certainly run into the varnish if it is applied using a brush. A spray-on lacquer should avoid this problem if it is applied in several thin coats, allowing one coat to dry before the next is applied. Spray-on coatings intended specifically for protecting inkjet prints are available, and good results should be obtained by using one of these in accordance with the maker's instructions.

More professional and even tougher results can be obtained by covering the panel with a transparent plastic material. The quickest and simplest method is to use a laminator. There is an alternative available if you do not have access to a laminator, and this is to use sheets of self-adhesive transparent plastic film. These can be obtained from larger stationers or online. Better protection is provided using the thicker gauge films, and they are easier to use. The thinner films can be tricky to handle and are more prone to problems with creases and air bubbles. Unfortunately, the thicker gauge films seem to be harder to obtain.

Most of these covering films will not damage the overlay if they have to be peeled back so that a second try at bubble-free results can be attempted. However, this assumes that the overlay has been printed on good quality paper or film, and there is no guarantee that damage will be avoided. Start with a slightly oversize piece of material, applying it initially at one end of the panel, and then work across the panel carefully pressing it down and into place. Small bubbles can be removed by bursting them with a pin and pressing down onto the panel to expel the air. It is then just a matter of trimming the excess film from the edges of the panel.

Mirror, mirror

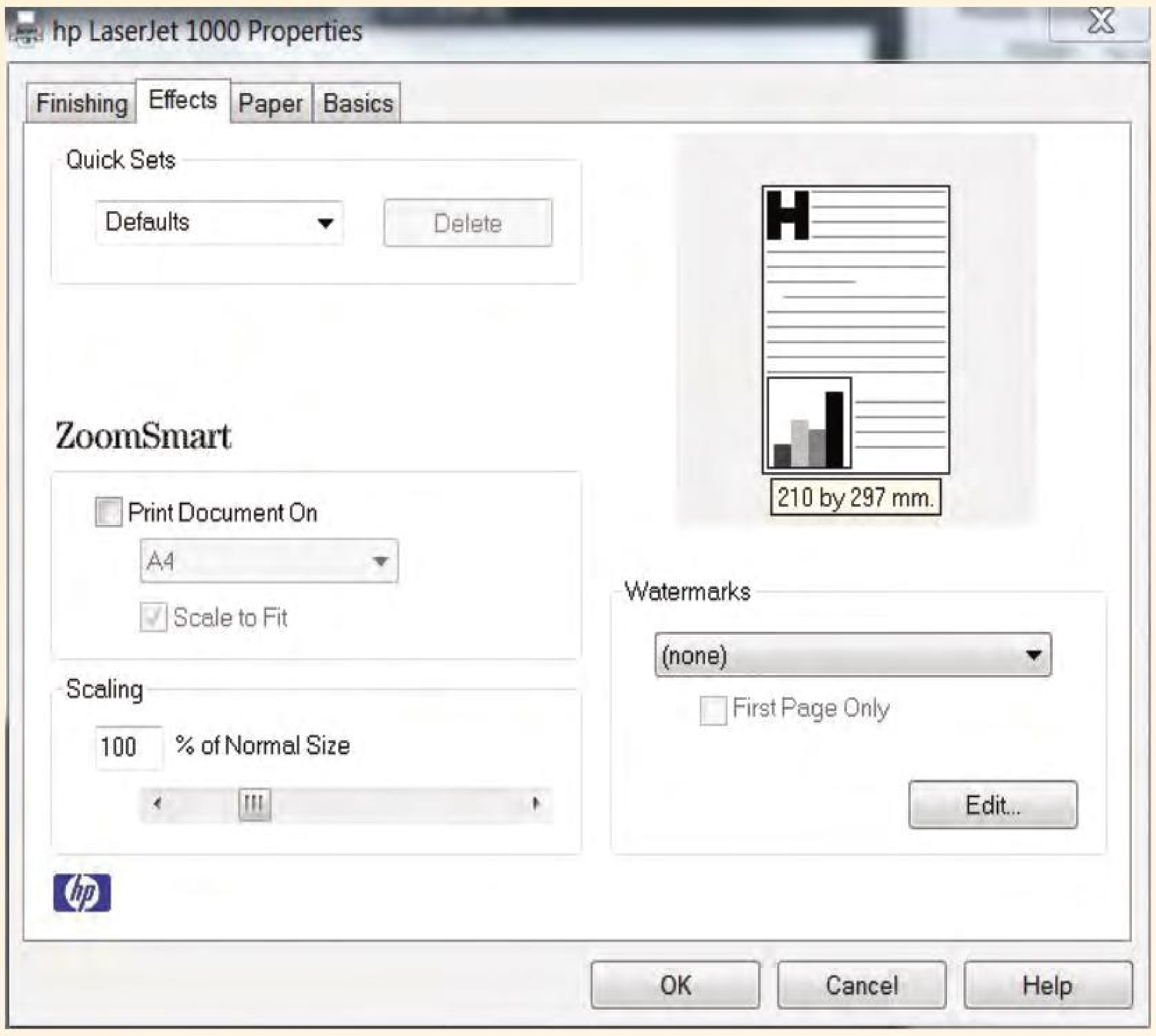
It is now long obsolete, but there used to be a photographic method of producing high quality overlays. A mirror image of the design was printed onto transparent film, and the overlay was then glued in place with the printed side against the panel. Fitting the overlay upside-down as it were, reversed the mirror image to give an image that was the right way round. This method provided very professional looking results and excellent durability with the film protecting the lettering.

It is possible to mimic this method using a computer and a printer with a mirror image of the design being printed onto transparent film. Self-adhesive transparent film is not suitable in this case, as it is not possible to print onto the adhesive side of the film. As pointed out in the previous article, most graphics programs have a facility that enables a designed to be 'mirrored' or 'flipped'. This is also a feature of many printer drivers. You therefore draw the design in the usual way, and then reverse it or print it as a reversed image. It might be necessary to experiment with different adhesives in order to find one that gives good results with no blotchiness or serious colouration, but a spray type should work well.

A matter of scale

When printing overlays it is important that precise 1:1 scaling is obtained, but there can sometimes be problems with a lack of accuracy. There is almost certainly an error in the printer settings if the printout is very much smaller or larger than its intended size. The default setting might be one that fits the material to the page size rather than printing actual size. The available settings depend on the particular printer in use, but there should be an actual size, 100 per cent or 1:1 option. It might be necessary to navigate a few tabs or submenus to find it (Fig.4), but it should be present somewhere in the printer settings. It is also worth checking the program's page settings. Are the dimensions in centimetres when you thought they were in inches, or something of this ilk?

It is likely that the problem is simply due to a lack of accuracy in the printer driver software if the error is quite small. Check that the installed printer driver is the most up-to-date one available for your printer. Whatever graphics software is in use, it should have the ability to scale the drawing up or down by any required amount. It is therefore possible to work around a lack of accuracy in the printer driver by altering the size of the drawing by the appropriate amount. Alternatively, the printer driver might permit 'fine tuning' of the scaling. Either way, a certain amount of trial and error will probably be required, but it should always be possible to get printouts at exactly the required size.



Quick Sets: Defaults

☐ Print Document On

A4

☑ Scale to Fit

Scaling: 100 % of Normal Size

Watermarks: (none)

☐ First Page Only

Fig.4. Any printer driver should have a facility that enables the scaling to be adjusted so that the design can be printed actual size. However, it might be tucked away somewhere in a submenu or under one of several tabs.

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READOUT

Matt Pulzer addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!

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All letters quoted here have previously been replied to directly

Email: editorial@wimborne.co.uk

☆ LETTER OF THE MONTH ☆

50th celebration

Dear editor

Your 50th celebration was timely as I was recently throwing out old magazines, including several you mentioned – now I'll keep the ones pictured for your 100th!

I inherited my love of electronics from my father, who was in radar during the war. His hobby stopped, and mine started with transistors. I preferred the low-voltage, hands-on approach that didn't threaten my teenage life when I got it wrong. That said, my brother gave up after his first dabble when he placed an IC the wrong way round and it exploded!

The advent of microprocessors and the fun (!) of assembler and I/O was a life changer for me. I gave up mechanical engineering for an electronics career, thinking about hardware until a wise man said software was the way forward. He was right, although a lifetime of tapping a keyboard has not been as much fun as burning the table with a soldering iron.

I try to enthuse youngsters but its hard going and I do wonder if the complexity is too daunting these days. Taking the back off a phone is like opening a modern car bonnet – you know the basics are in there somewhere, but where to start? I still marvel at some of the throw-away electronic gadgets that someone in China has designed and produced to sell for pennies across the other side of the world.

While I still enjoy dabbling, I do find setting up and programming modern microprocessors is complex and takes a lot of time just to get it going. The Arduino is a breath of fresh air and has re-awakened my interest, likewise your article on the GPS logger – excellent.

While we've come a long way with electronics and expect real-time TV from around the world it still impresses me that we can receive signals from Voyager 2 spacecraft. Launched in 1977, it's over 19 billion kilometres away and has a 16 baud signal produced by a 20W radio transmitter. The power reaching our antennas is '20 billion times smaller than the power of a digital watch battery' – someone likened it to seeing a match flare on the moon.

Paul Shelley Suffolk, UK

Matt Pulzer replies:

Thanks Paul, and here's to another 50 years of electronics publishing. Like you, I have marvelled at our ability to pick up signals from Voyager – it truly is a remarkable piece of electronics detection.

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Reminiscences

Dear editor

When I was at school in 1964 I brought the first edition of *Everyday Electronics* from a newsagents in Cowley Road, Oxford and had it put by for me every month. The cost of two shillings and sixpence came out of my paper round money of one pound, two shillings per week.

The following year, I built the oscilloscope in the March, April and May editions. It used valves, five double triodes and one double diode rectifier and the cathode ray tube. It wasn't easy getting the parts through the post, but I succeeded, made it and it worked. I was just 14 years old at the time.

I kept my magazines for many years, but lack of space meant that eventually they had to go. However, I think I may still have the resistor colour code calculator somewhere.

David Day, by email

Alan Winstanley replies:

Thanks for writing with some reminiscences – those were the days! I can well appreciate that making a fully-functional

CRO at such a young age would have been a remarkable and immensely satisfying achievement.

For my own part, I was a Saturday lad at WH Smiths in the mid-1970s and I think I could buy Everyday Electronics *on a staff discount. I saved up my modest shopworker's earnings to send away for components from Home Radio, Maplin, Henrys Radio and Laskys, after which I would take over my father's garage and start building my projects. I have been glued to* EPE *ever since!*

Rolls-Royce

Dear editor
Great to see your anniversary edition, and your celebration of a significant event – a particularly memorable one for me. I was in my 'O' level year at school and one day our physics teacher came in with a handful of magazines. He proceeded to introduce it and handed them out to anyone interested – it was the first issue of *Practical Electronics*.

I already had an interest, ever since I was given a Heathkit junior radio kit (remember them?) for Christmas a few years earlier. I jumped at my teacher's offer and read it from cover to cover. I immediately took out a subscription that ran for the best part of a decade. I even bought the binders, and added them to an ever-growing library. I still have those bound sets! This set me off on a lifetime hobby *and* career – from an apprenticeship to a 34-year career in electronics and computing for Rolls-Royce in Bristol.

My earliest build project was the 5W audio amp featured in that first issue. It sounded wonderful! I finally took retirement from all work in July last year and we have recently had an extension built, which has allowed me to set up a 'man cave' – I can feel some electronics building coming on again soon!

Alan's review was a great way to celebrate that 50th – many congratulations on your anniversary. I've bought your 50th edition in 'e' form for my iPad so no need for binders now! I'll be keeping in touch.

Andy Pearson, by email

Matt Pulzer replies:
Fantastic to hear Practical Electronics *played a small part in launching a Rolls-Royce career.*

Progression

Dear editor
First, congratulations to the magazine on reaching 50. I read with great interest Alan's article, *50 Years Anniversary*, in the November 2014 edition.

I built my first radio receiver when I was 12 years old. It was a reaction receiver and used two EF50 valves. I started out reading electronics magazines in the 1960s. I think the first one was called *Radio Constructor* and was in an A5 format. Then I started reading *Practical Electronics*.

I was in Australia in the 1970s where I read *Electronics Australia*. Then in the 1970s and 1980s it was *Electronics Today International* and now finally *Everyday Practical Electronics*.

I could not keep all my magazines due to space limitations. However, I did keep constructional articles and information which I thought may be of use in the future. I have been looking over these and particularly enjoyed these three:

1. The design and construction of electronic 'animals' or machines with artificial intelligence, which showed how to build your own robot. *Practical Electronics*, November 1968 by FE Bennett

2. Rain alarm project using a CMOS 4011 logic chip, *ETI*, April 1978

3. 'Designer's Notebook' looking at the relatively new 555, *ETI*, December 1979.

Peter Hardy, Cheltenham, Glos.

Alan Winstanley replies:

It is fascinating to look back and witness the emergence of early concepts such as 'electronic animals' as the potential to use new technology in organic-like applications was explored.

As I discussed in the first of my anniversary articles, the world grew smaller and readers' interest in hobby electronics continued to evolve (or sometimes wane) and a multitude of UK magazine titles coalesced to form today's EPE *– but, as you have experienced yourself, let's not forget that a thriving radio and electronics scene also existed in Australia as well as the US.*

Some intense rivalry between the publishers of ETI *and* Electronics Australia *ensured that enthusiasts had plenty of choice 'down under'. The Australian magazine landscape was not immune to the whims of the electronics hobbyist though and, just like in Britain, various magazine titles turned over or merged, and in fact* EA *is now owned by* Silicon Chip *some of whose top-quality designs now appear each month in* EPE.

I mentioned how the Space Race triggered many electronic advancements, but many UK readers may not be aware that almost every mainstream hobby electronics title in the US, some of them originating from the turn of the 20th Century, has now closed down and long-standing titles such as Electronics Now *and* Popular Electronics *are no longer with us. (Wikipedia is a good source of background and history, if you want to learn more.) History proves that the publishers of* EPE *have always been progressive and committed to meeting new challenges head on, but more than anything it's thanks to having a dedicated readership that we can bring a vibrant and topical hobby electronics magazine to you every month. So thank you, readers, for your continued support and loyalty!*

Drawing *EPE's* schematics

Dear editor
I'm a fan of *EPE* and I want to ask about the program used to draw electronic circuits (schematic and PCB) in your magazine.

Ahmed Mohamed, by email

Matt Pulzer replies:
We generate diagrams with a number of software packages. The main one is Adobe Illustrator. We created our own symbol library from scratch, which does not take as long as you might think.

The advantage of Illustrator is that it is a very flexible package, which works well with other publishing packages such as Photoshop and InDesign. However, the diagrams it produces are 'dumb' there is absolutely no in-built analysis such as you might find with Circuit Wizard.

IF YOU HAVE A SUBJECT YOU WISH TO DISCUSS IN READOUT PLEASE EMAIL US AT:

editorial@wimborne.co.uk

WHIZZKITS
Electronics Builder's Kit

Whizzkits Electronics Builder's Kit

Mike Tooley reviews this brand new educational product from Spiratronics

WHIZZKITS is the brainchild of Bob, a Spiratronics employee, affectionately known as 'Grandad Bob'. After many years working in the electronics industry, and as a home constructor, Bob felt that now would be a good time to put something back, something that could benefit individuals starting out in electronics.

The result is Bob's 'Electronics Builder's Kit' (Level 1). It is designed to give a pathway for anyone wishing to get started in electronics. The kit was designed to meet several objectives, including being informative in such a way that interest was not drowned in a sea of words, technical jargon and schematics. It also had to be priced so that it was within reach of the vast majority of people. Bob says that, 'Above all we were determined that when the constructor "came out the other end", they would be wiser, more confident about electronics and the way things worked, and hopefully have an appetite to learn more'.

What's in the box?

In addition to the instruction manual, the kit comprises around 50 components, including resistors, capacitors, jumper leads, switches, diodes, ICs, LEDs, a relay, a miniature loudspeaker, an electret microphone, and a battery. A set of pre-made connecting links are provided, as is a 9V PP3 battery and associated connector. There is also a small trimming tool for adjusting the pre-set potentiometer supplied with the kit – and, there is even a small piece of emery cloth for cleaning connections. The designers have thoughtfully colour coded the two 8-pin DIL chips with dots so that they cannot be confused.

Projects

The five main projects that can be built with the kit are: a light-operated switch (which can be extended in order to drive a small relay); a simple audio amplifier; a time delay (which can also be extended using a small relay); a trigger/reset device; and a heads and tails game. The projects are well thought out and cover a variety of different circuits ranging from amplifiers to comparators and light sensors to timers. The circuits are based on a subset of common low-cost semiconductor devices, including LEDs, diodes, NPN and PNP transistors, a 741 operational amplifier and a 555 timer.

Instruction manual

The kit includes an illustrated 30-page instruction manual. Crowd funding was used to secure the necessary capital to pay to have the booklet set and printed, along with the outer display packaging. The manual is divided into three sections: Getting Started, Projects, and Help and Troubleshooting. The first section describes the use of the prototyping board, explains how light-emitting diodes

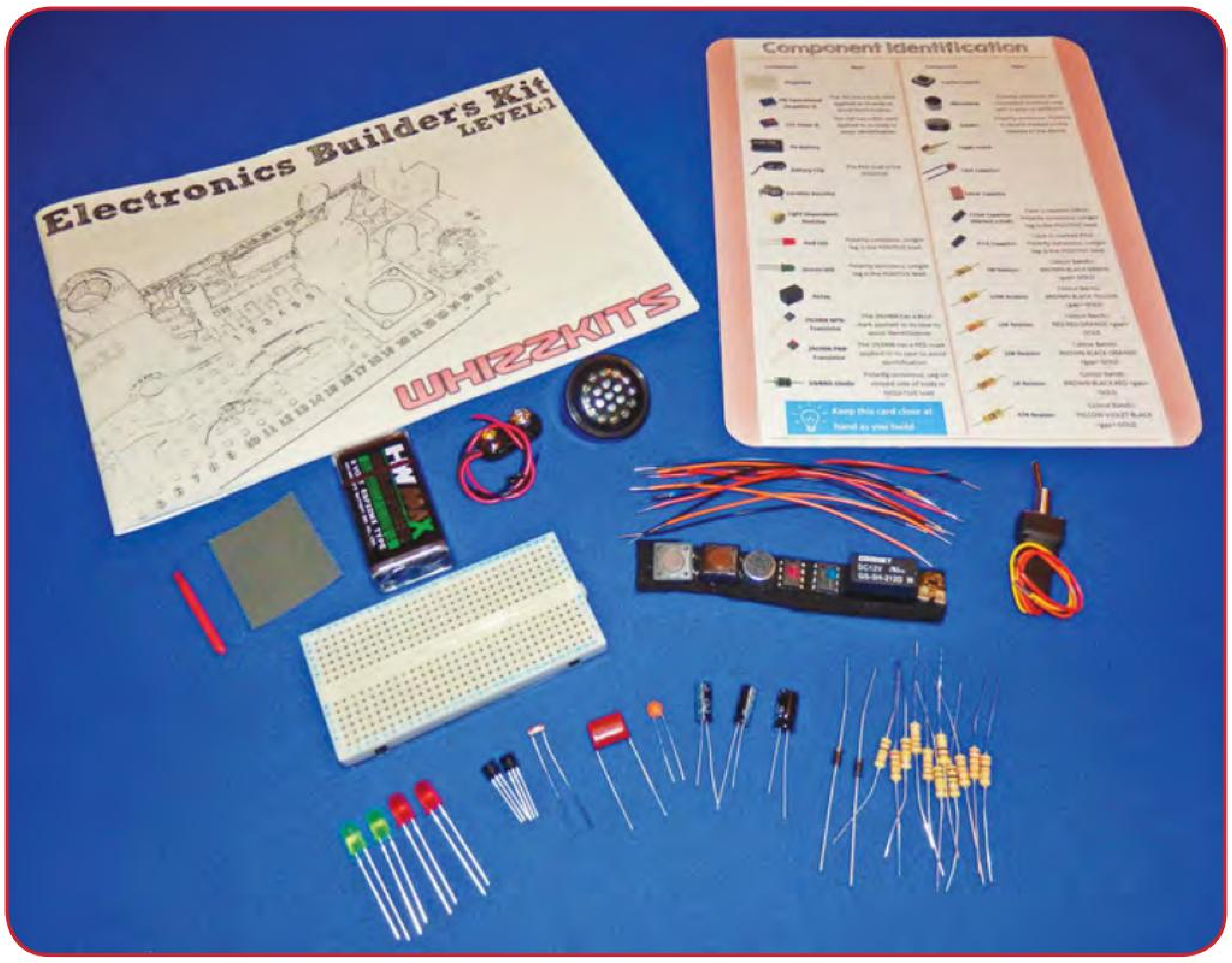

Fig.2. Contents of the Electronics Builder's Kit

(LEDs) operate, and shows how components are connected to produce simple working circuits. The section also explains the use of current-limiting resistors and includes an explanation of switching.

Each of the five projects is described in detail in the following section. Circuit diagrams, together with accompanying layout diagrams are provided, and a detailed step-by-step connection list for each project is included in a section headed 'Time to Build'.

The final section contains essential information on component identification, together with brief information on the 555 and 741 devices. After a brief introduction to resistors, capacitors and Ohm's Law, this section describes variable resistors, transistors, diodes, relays and light-dependent resistors. The manual concludes with a useful page on troubleshooting.

The use of a rather small font and somewhat indistinct colour meant I found several of the circuit diagrams difficult to read. This was particularly the case with Project 1 (Light Sensitive Switch). Other projects didn't suffer quite so badly, but the authors should consider making improvements to the circuit diagrams when the booklet is next reprinted.

In conclusion

Some careful thought has gone into putting this kit together and it certainly achieves its aim of making electronic circuits accessible to newcomers at an affordable price. Spiratronics currently have more kits on the drawing board, including an Arduino kit, a microcontroller kit, and a number of component supply kits. It would be good if at least one of these kits could include and explain the use of a multimeter. This topic is not covered in the Level 1 kit and it could be a valuable aid when fault finding.

The individual projects are well conceived and provide a range of varied and useful activities. They are ideal for individual learners, as well as students following GCSE-level courses in technology and electronics. The projects could also provide the basis for more advanced work, such as using the light-sensitive switch in a simple security system with the manual trigger/reset device being incorporated in a safety 'lock out' system.

Last, if you would like to see one of the projects in action there is a YouTube video (sadly with no sound) at **https://www.youtube.com/watch?v=G44hC8y_iN8**

Box

The Level 1 'Electronics Builder's Kit' can be ordered from Spiratronics (**www.spiratronics.com**) and is priced at £17.99 (inc VAT) with discounts for multiple quantities. The order code for the kit is WK1-12. The kit currently also includes a discount code which results in a saving of 20% on all further orders for components included in the kit.

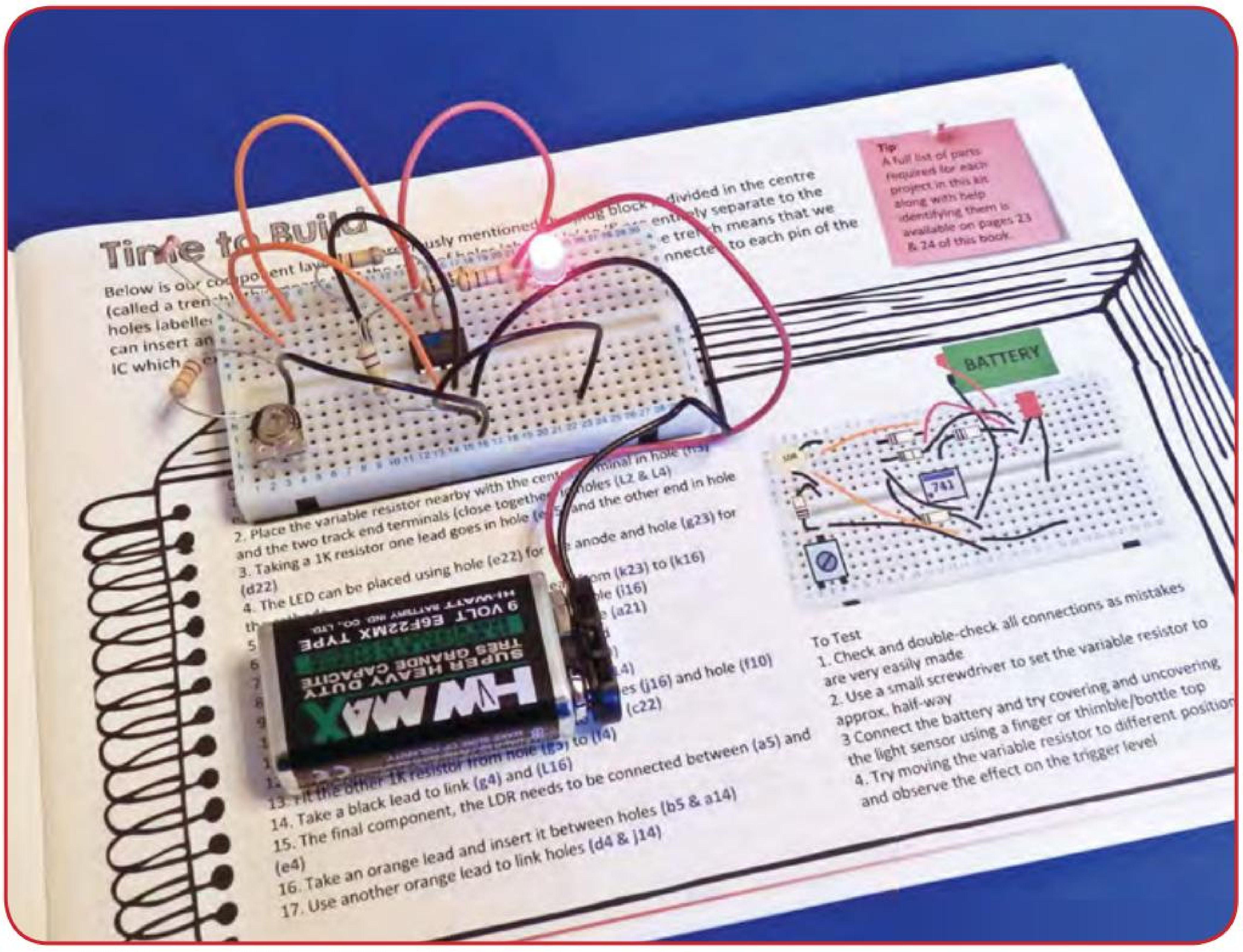

Fig.3. On test: the light sensitive switch project

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AUDIO OUT

By Jake Rothman

Test-bench amplifier – Part 2

Balanced input and gain control

Our power amp has low input impedance, so it needs an op amp to drive it (see Fig.5). A differential stage can then be used to provide a balanced input. Its hot and cold inputs can then be flipped to cancel out the inversion in the power amp. A gain control pot can now be inserted between the two stages.

The pot can tolerate a small offset across its track but not on its wiper. A film capacitor is used on the input to the power amp to prevent any leakage currents being transmitted – although this is only effective when the amp is in normal mode, low-Z with bass boost. An electrolytic is avoided by using feedback to boost the capacitor's apparent value. Finally, a classic pot trick is used here – the low input resistance loads the linear pot to provide a log action.

The inputs to the op-amp have no coupling capacitors because the input resistors provide protection to the op-amp. However, DC on the inputs will cause the pot to scratch or in the worst case saturate the op amp. Since the amp is designed for use with an external preamp it will not normally be a problem.

Capacitor-coupled output

A 2mF bank of non-polarised capacitors wired in parallel protects the speaker from DC offsets (see *Audio Out*, *EPE*, August 2014). It also limits the short circuit current of the output stage and prevents damage from DC entering the amplifier when used for circuit development. The output capacitor is included in the negative feedback loop to reduce any distortion and ESR. A 330kΩ resistor provides the DC feedback path around the amplifier. Since its value has to be high, a corresponding DC high resistance has to be incorporated in the inverting input to ground. The resistance is bypassed with a 470nF ceramic capacitor to reduce noise. This is a preset to allow

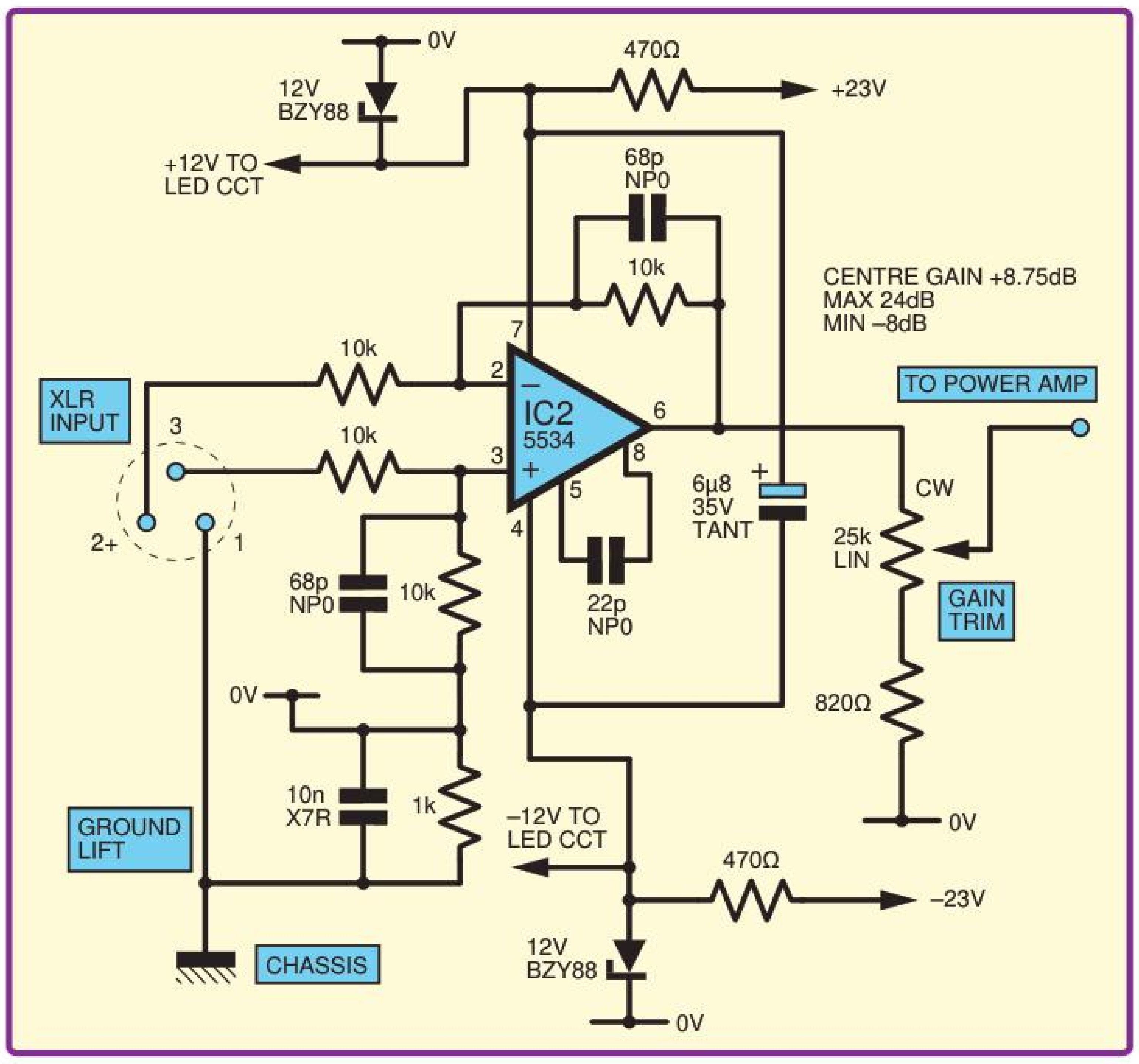

0V
470Ω
+23V
12V
BZY88
+12V TO
LED CCT
68p
NP0
10k
CENTRE GAIN +8.75dB
MAX 24dB
MIN –8dB
7
10k
2
TO POWER AMP
XLR
INPUT
3
10k
IC2
5534
6
3
8
CW
5
6µ8
35V
TANT
2+
1
4
25k
LIN
68p
NP0
10k
22p
NP0
GAIN
TRIM
0V
820Ω
10n
X7R
1k
–12V TO
LED CCT
0V
GROUND
LIFT
470Ω
–23V
12V
BZY88
CHASSIS
0V

Fig.5. The balanced input stage

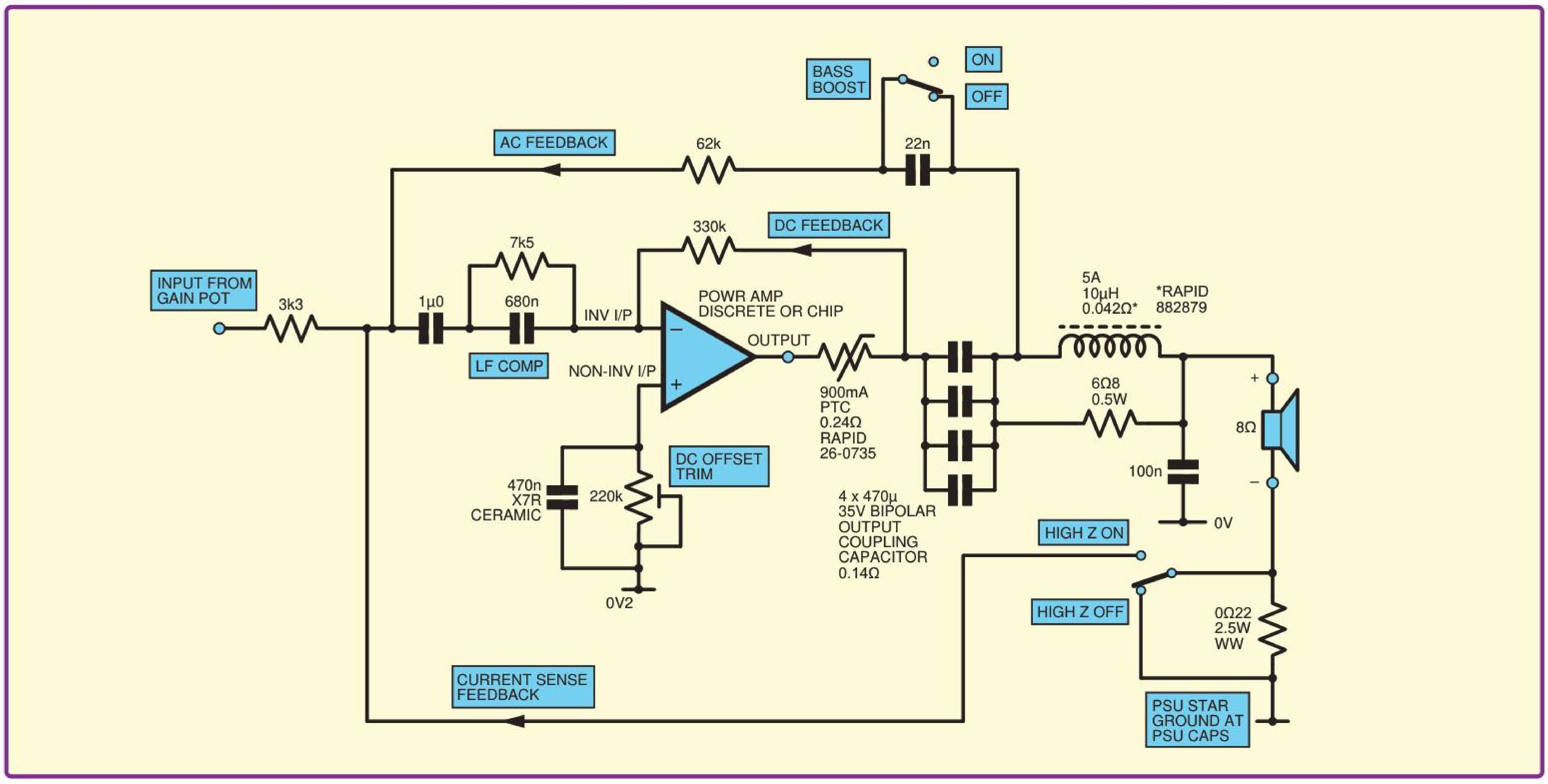

BASS
BOOST
ON
OFF
AC FEEDBACK
62k
22n
330k
DC FEEDBACK
7k5
INPUT FROM
GAIN POT
3k3
1µ0
680n
INV I/P
POWR AMP
DISCRETE OR CHIP
5A
10µH
0.042Ω*
*RAPID
882879
OUTPUT
LF COMP
NON-INV I/P
900mA
PTC
0.24Ω
RAPID
26-0735
6Ω8
0.5W
+
8Ω
DC OFFSET
TRIM
470n
X7R
CERAMIC
220k
100n
–
4 x 470µ
35V BIPOLAR
OUTPUT
COUPLING
CAPACITOR
0.14Ω
0V
HIGH Z ON
0V2
HIGH Z OFF
0Ω22
2.5W
WW
CURRENT SENSE
FEEDBACK
PSU STAR
GROUND AT
PSU CAPS

Fig.6. The circuitry around the basic power op amp module in Fig.1 (see Part 1 in November 2014)

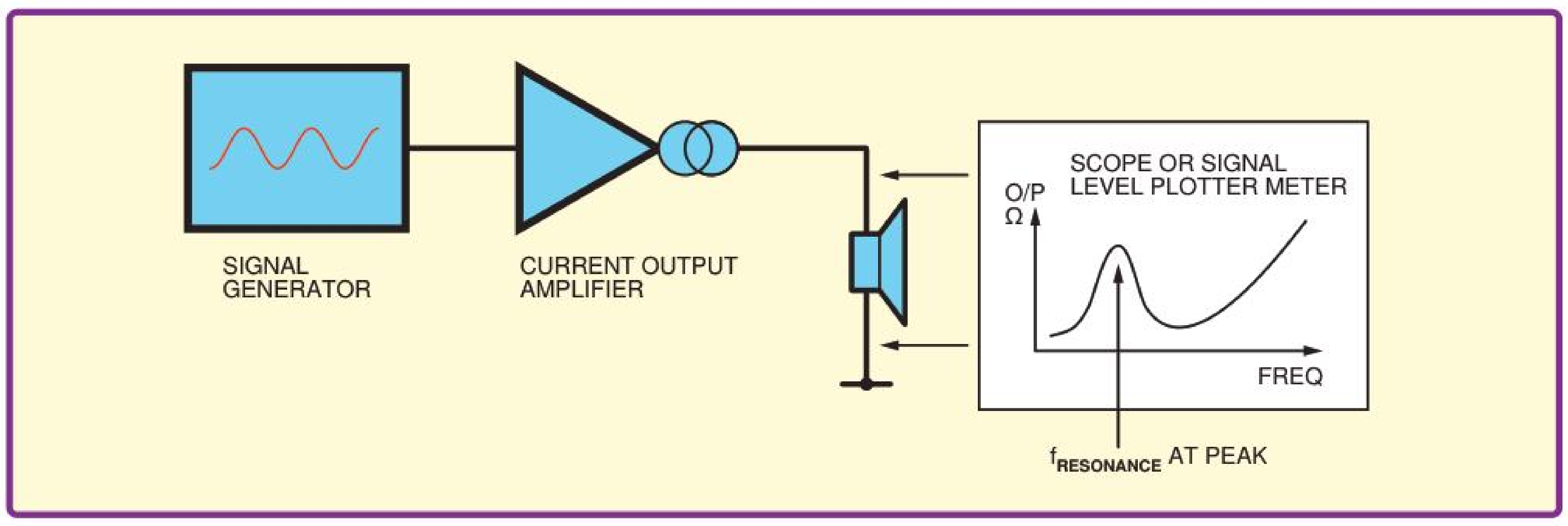

SIGNAL GENERATOR
CURRENT OUTPUT AMPLIFIER
SCOPE OR SIGNAL LEVEL PLOTTER METER
O/P Ω
FREQ
$f_{RESONANCE}$ AT PEAK

Fig.7. Using the high-impedance constant-current output to measure the resonant frequency of a loudspeaker driver

the DC offset of the amp to be nulled out to ensure symmetrical clipping.

Frequency response

Where negative feedback is placed around coupling capacitors, an attenuation network is required to reduce the low frequency open-loop gain to prevent oscillation. I found equations to do this, but they didn't work and the values had to be determined experimentally using a 'scope and signal generator. In this circuit, there was a 3.5dB peak at 6.1Hz. A low frequency step network consisting of a 680nF cap and 7k5 resistor corrected this.

Bass boost

Since small speakers with four to five-inch drivers are used on test benches, a small amount of switchable boost (+4dB) is available around 100Hz. I sometimes use it since I don't want a sub-woofer under the bench.

High-impedance output

A switchable current-sensing resistor generates a high output impedance of 50Ω suitable for testing the resonant frequencies of loudspeakers and driving unusual loads. I also use it to current-drive loudspeakers which can reduce intermodulation distortion from the electromagnetic drive system. The basic circuit of this was shown in Fig.6. Note that since it generates additional negative feedback, the gain reduces by 18.8dB when an 8Ω load is used. Fig.7 shows how to find the resonant frequency of a loudspeaker, it's the frequency at the 'hump'.

Error indicator

In any feedback amplifier, the feedback acts so as to make the voltage on the inverting and non-inverting inputs the same. Under overload and fault conditions a voltage difference occurs between these two points and this is used to turn on a red LED (see Fig.8). A bridge rectifier arrangement smooths the pulses feeding the LED. This LED is incorporated with a green power LED in a dual-colour device. A transistor is used to turn off the green LED when the red LED is on. The resulting unique red/green flickering action is very noticeable. Note that the LED glows red briefly when the amp settles during turn-on and off.

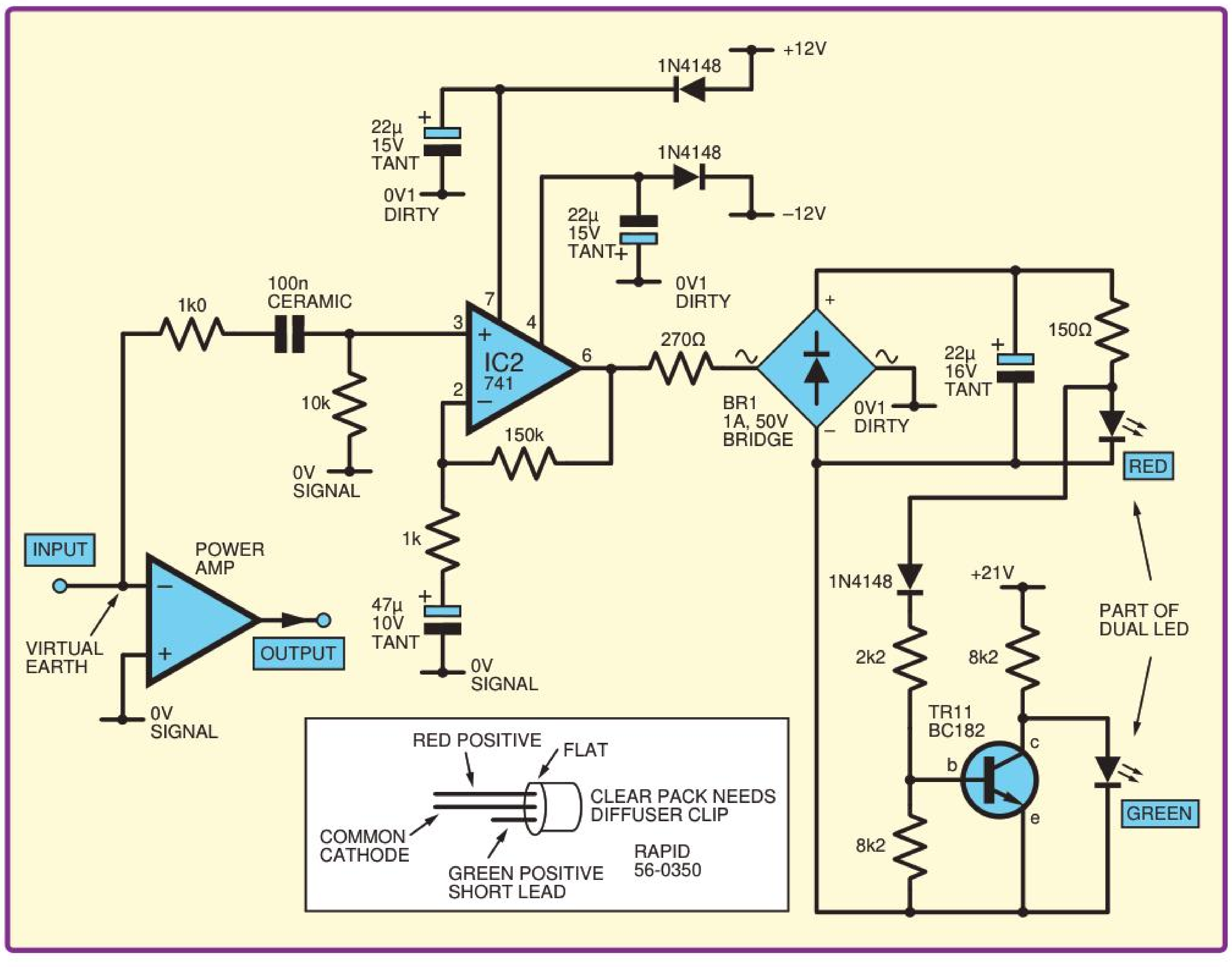
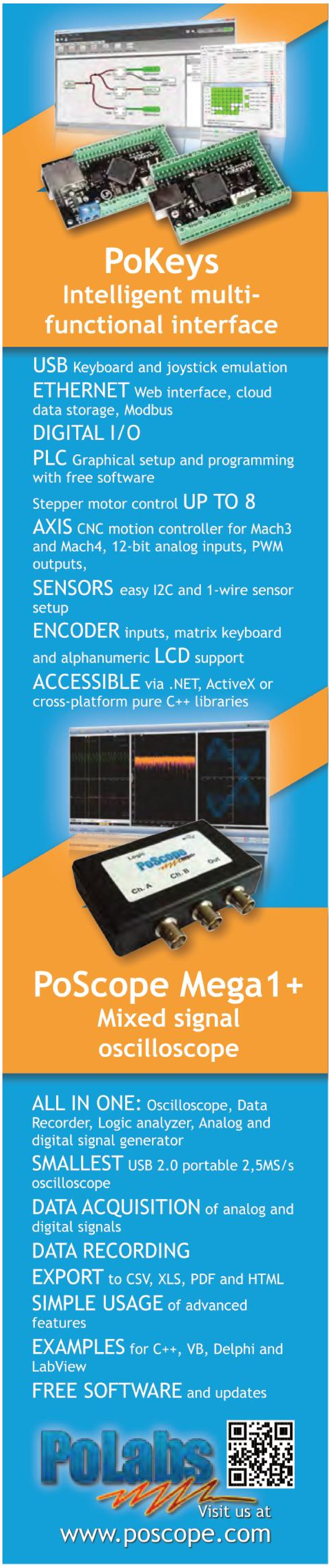

+12V
1N4148
22µ 15V TANT
0V1 DIRTY
1N4148
–12V
22µ 15V TANT
0V1 DIRTY
1k0
100n CERAMIC
10k
0V SIGNAL
7
4
3
2
6
IC2 741
150k
270Ω
BR1 1A, 50V BRIDGE
0V1 DIRTY
22µ 16V TANT
150Ω
RED
1k
47µ 10V TANT
0V SIGNAL
INPUT
POWER AMP
VIRTUAL EARTH
OUTPUT
0V SIGNAL
1N4148
+21V
2k2
8k2
TR11 BC182
b
c
e
8k2
PART OF DUAL LED
GREEN
RED POSITIVE
FLAT
CLEAR PACK NEEDS DIFFUSER CLIP
COMMON CATHODE
GREEN POSITIVE SHORT LEAD
RAPID 56-0350

Fig.8. The combined LED error/power-on indicator circuit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SENSORS easy I2C and 1-wire sensor setup
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EXPORT to CSV, XLS, PDF and HTML
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BY IAN BELL

Triacs and opto-isolators

A RECENT *Chat Zone* discussion, started by ***atferrari***, concerned a circuit in which a triac was driven by an opto-isolator. The discussion raised issues such as conditions under which triacs switch, snubbing and opto-isolation. The specific use of the circuit discussed in the thread was not stated, but commonly used opto-isolator to triac circuits include AC power controllers and solid-state relays.

Solid-state relays

Just like their mechanical counterparts, solid-state relays allow a low-power signal to switch a much higher power load on and off without it being necessary to have an electrically conductive path between the two. This isolation provides enhanced safety. Solid-state relays can switch DC, where typically a silicon-controlled rectifier (SCR, also known as a thyristor) is used as the power switch. For AC switching, triacs are used.

Solid-state relays are smaller, quieter, faster and longer lasting than mechanical ones. They do not suffer from switch bounce or sparking and are less likely to be affected by adverse conditions such as vibration and mechanical shock. However, they do have some potential disadvantages compared with mechanical relays. Spurious (unwanted) switching caused by electrical noise is more likely, although preventable by suitable design and, unlike mechanical relays, solid-state relays are not truly open circuit when off – some leakage current will flow.

Triac control

In AC power controllers, the triac is switched on part way through each half cycle of the supply waveform and hence provides varying power to the load, dependant on the proportion of the waveform for which it is on. Such controllers can be built with all the circuitry directly connected to the AC supply, including a floating low-voltage DC supply to a microcontroller or dedicated controller IC. In such cases, which includes traditional domestic lamp dimmers, opto-isolators are not used, but of course the whole unit must be suitably insulated from the user. In other situations, for example control of stage lighting, opto-isolators are used between the control circuits and power control devices to ensure safety.

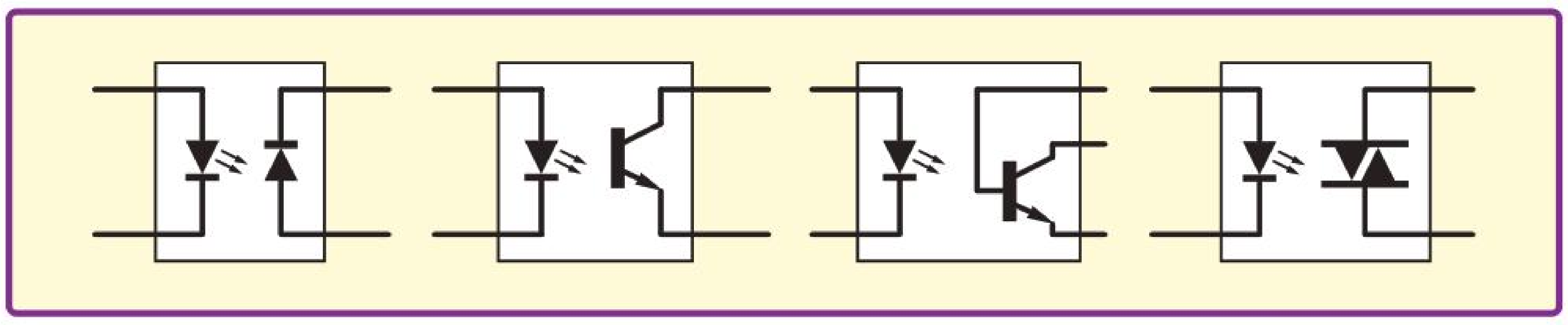

Fig.2. Various opto-isolators

We have mentioned lamp dimmers as this is a well-known, traditional use of triac-based power control. However, non-dimmable low energy bulbs (both compact fluorescent lamps (CFLs) and LED bulbs) must never be connected to a dimmer – the result may be very dangerous. Basic triac dimmer circuits may perform very poorly with dimmable low energy bulbs and other circuit techniques may be more appropriate. For example, trailing edge dimmers switch the power *off* part way through the AC cycle, which is something that cannot be achieved with a basic triac circuit. There are of course still many other applications for triac switching and control.

Power switch device basics

Triacs are a member of a family of devices that also includes diacs, SCRs and more exotic components such as MOS thyristors. All these devices are bistable – that is, they have two states of operation, with different levels of conductivity between the main terminals in the two states. In the 'on' state they have low impedance, which is maintained as long as the current through the main terminals remains above a certain limit known as the 'holding current'. In the 'off' state they have very high impedance, which is maintained as long as the applied voltage is below a certain limit known as the 'forward breakover voltage'. Diac and triac circuit symbols are shown in Fig.1.

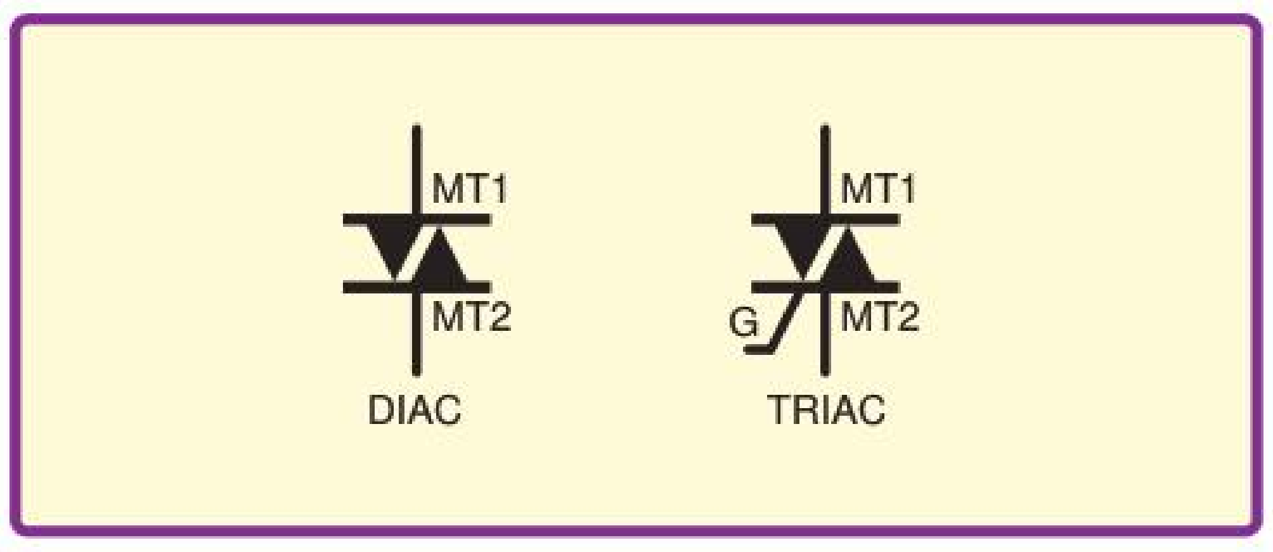

Fig.1. Diac and Triac symbols

Optical isolation

An opto-isolator (also known as an opto-coupler) comprises an LED (typically infrared) and detector sealed in a single package. Various opto-isolator symbols are shown in Fig.2. The detector may be a photoresistor, photodiode, phototransistor or other light-sensitive device. Switching the LED on causes light to fall on the detector, switching it on, or changing its effective conductivity. Opto-isolators are most commonly used to transmit digital data and power switching control signals (as in the solid-state relay), but analogue signals can also be transmitted.

For triac driving (see Fig.3) the detector is usually a phototransistor or a complex device that behaves like a diac/triac triggered by light (as in Fig.3). In some opto-isolators, further control circuits are present, which ensure switching close to the zero crossing of the mains waveform.

In the circuit in Fig.3, a microcontroller or other logic circuit runs from a conventional low-voltage power supply and supplies the control input to switch on the opto-isolator LED and hence the load. The opto-isolator keeps the triac/load and control circuit electrically separate so we do not have to worry about any interaction between them. However, this will only be of any use if the overall construction of the system is also safe. Correctly designed, implemented and constructed opto-isolated power switching is very safe, but it is worth mentioning that working on prototyping and debugging such circuits may expose the developer to hazards that the end user would not experience. **This type of work should only be carried out if you are suitably experienced and competent**.

Connection terminology

Returning to look at the power-switching semiconductors in more detail, we note that some of these devices, such as SCRs, conduct in

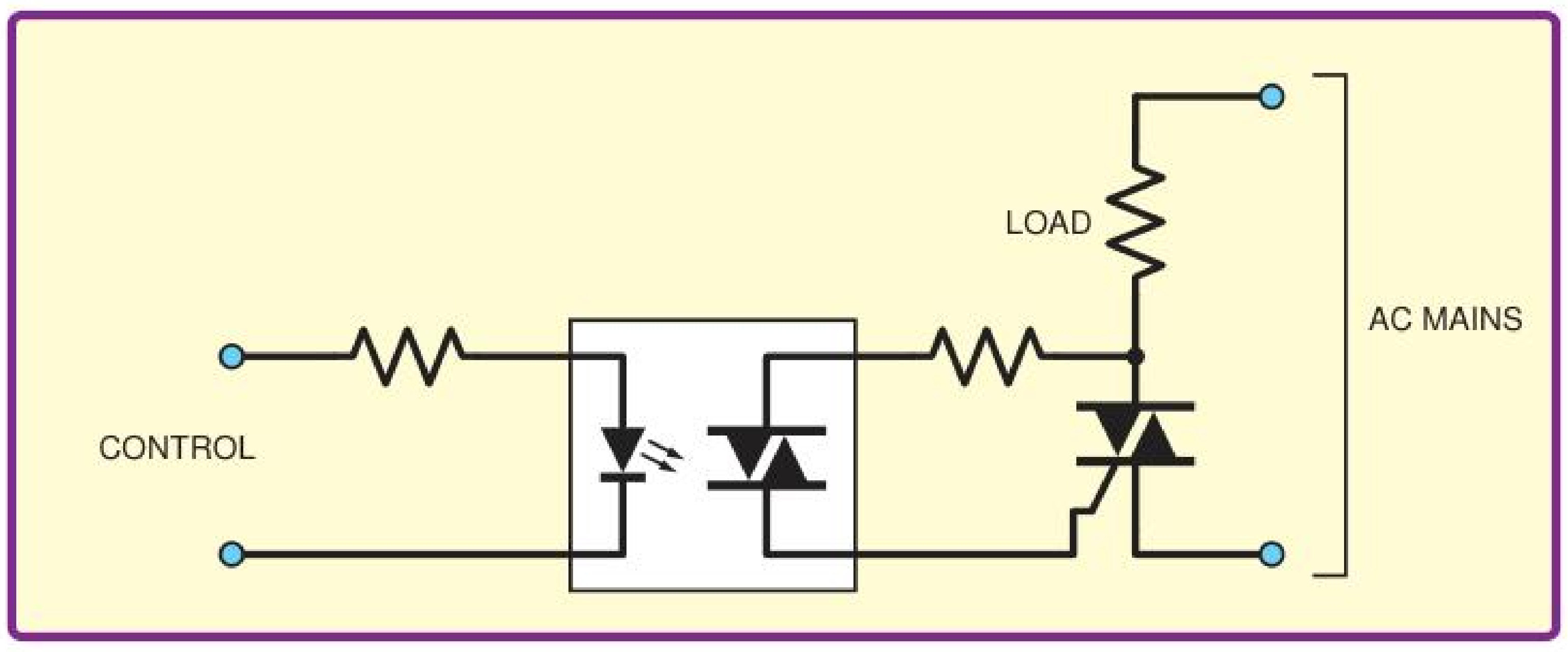

Fig.3. Opto-isolated triac control

one direction and behave as reverse-biased diodes in the other direction – for these devices, the main terminals are designated anode (A) and cathode (K). Other devices, such as diacs and triacs, conduct in both directions; here the main terminals are simply called main terminal 1 (MT1) and main terminal 2 (MT2), as shown in Fig.1.

SCRs and triacs have a third terminal known as gate (G). The higher the current into the gate the smaller the forward breakover voltage becomes. Thus, applying a sufficient pulse of current to the gate will switch the device into the 'on' state. Once in the on state, the gate current need not be maintained due to the bistable action mentioned above. The device remains on until the main current falls below the holding current. For the photosensitive diac/triac device used in opto-isolators (as in Fig.3) light acts like a gate signal in a triac, reducing the breakover voltage and causing the device to switch on with a relatively small voltage applied to its main terminals.

AC/DC switching

For DC switching with an SCR, the power must be explicitly removed to switch the device off, but for AC switching with a triac, the device will switch off at the end of the half cycle during which it was triggered – this is because the current through the device will drop below the holding current as the AC voltage drops towards 0V. Thus, to switch a load on continuously a triac has to be triggered during every half cycle of the AC waveform. This happens automatically in the circuit in Fig.3 when the LED is on because the photosensitive diac device will trigger directly from the AC supply in every cycle. The resistor connected to the opto-isolator output is to limit the current through the photosensitive diac/triac.

As already mentioned, triacs are often used in power control, rather than the basic on/off switching of a solid-state relay. This is achieved by manipulating the point in the AC half-cycle at which the device is triggered (this is known as phase control). The later the power is switched on the less power is delivered to the load.

Quadrant switching

The fact that triacs can conduct in both directions and can be triggered by gate currents of either polarity leads to four possible triggering scenarios, or 'quadrants', as illustrated in Fig.4. Positive half cycles of the AC waveform correspond to quadrants I and II in the upper half of Fig.4. The triac's MT1 terminal is positive with respect to MT2. Negative half cycles of the AC waveform correspond to quadrants III and IV in the lower half of Fig.4. The triac's MT2 terminal is positive with respect to MT1.

Situations where the trigger circuit is sinking current – so that the trigger current flows out of the gate (negative gate current) correspond to quadrants II and III on the left half of Fig.4. Situations where trigger circuit is sourcing current – so that the trigger current flows into the gate (positive gate current) correspond to quadrants I and IV on the right half of Fig.4.

Triacs are typically most sensitive (require lower trigger currents) in quadrants I and III. They are slightly less sensitive in quadrant II and least sensitive in quadrant IV. Some triacs cannot be triggered in quadrant IV. Datasheets typically refer to 'four-quadrant' and 'three-quadrant' triacs to indicate whether or not the device will switch in quadrant IV. Three-quadrant triacs are typically trading off this gate trigger option against sensitivity to triggering by rapidly changing main terminal voltage. The circuit in Fig.3 triggers the triac in quadrants I and III.

The trigger current required by a triac increases as the switched current increases – the opto-isolator output, or other circuit directly controlling the triac must be able to handle this current. The gate current must also be applied for sufficient time to turn on the triac. This turn on time will be specified in the datasheet and will typically be in the order of microseconds. The specified time will assume a large voltage across the triac, but if the trigger pulse is applied early in the AC cycle it may have to be held for longer to ensure that the triac is conducting above the holding current before the trigger is removed.

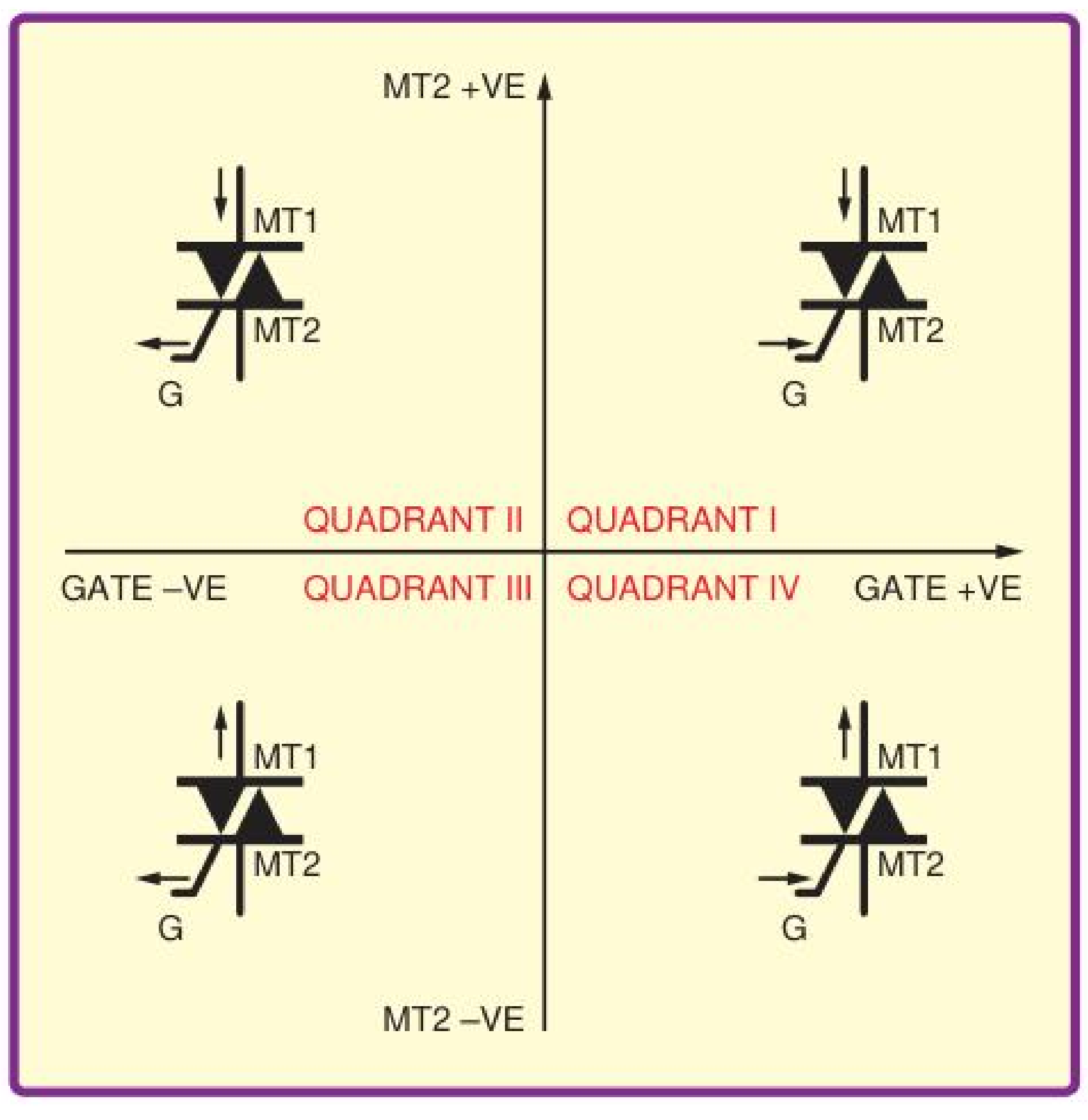

Fig.4. Triac quadrants

Switching off

Another timing issue arises in power control circuits. At the low-power end of the control range, the opto-isolator LED is pulsed late in the AC half cycle. As indicated above, it must be on long enough to switch the triac on (the minimum will probably be much less than a millisecond) but it must also switch off in sufficient time before the AC zero crossing. If it does not do so the triac may not switch off at the zero crossing and will therefore remain on during the next half cycle. This minimum off time may be in the order of hundreds of microseconds.

The gate current is unfortunately not the only way to turn on an SCR or triac. A sufficiently fast rising main terminal voltage can also do so due to the capacitances inherent in the device's structure. This is similar to the dV/dt-induced turn on of MOSFETs discussed last month. As with MOSFET power switches, snubber circuits (resistor and capacitor in series) can be used to reduce the rise-time of voltages across the device, as shown in Fig.5 (R_S and C_S).

There are a couple of scenarios in which high rates of change of terminal voltage may inadvertently trigger the triac. The first is simply by applying a fast-changing voltage to the main terminals and is referred to as 'static dV/dt'. The second scenario occurs when the triac tries to turn off with an inductive load. The resulting voltage spike from the inductor may cause the triac to turn back on again. This is referred to as 'commutating dV/dt'. Commutating dV/dt is less than static dV/dt and therefore is more likely to cause difficulties.

Over-voltage protection

In addition to the snubber, which will protect the triac from fast transients at voltages below its maximum voltage, it may be necessary to protect the triac from over-voltage transients. This can be achieved by a metal-oxide varistor (MOV). These exhibit a very high resistance up to their varistor voltage, at which point they conduct. This is somewhat similar to a diode switch-on, but occurs for voltages of either polarity and typically at much higher voltages.

Making a triac less sensitive to fast voltage changes may mean that the snubber is not required, reducing component costs. Such devices are marketed as 'snubberless triacs' or 'alternistors' or high commutating triacs. Loss of fourth-quadrant triggering in these devices is not a major problem because most triac circuits do not use triggering in the fourth quadrant anyway.

The term 'random phase' opto-isolator is sometimes used for devices such as those used in the circuits in Fig.3 and Fig.5. This simply means that the control input to the LED can

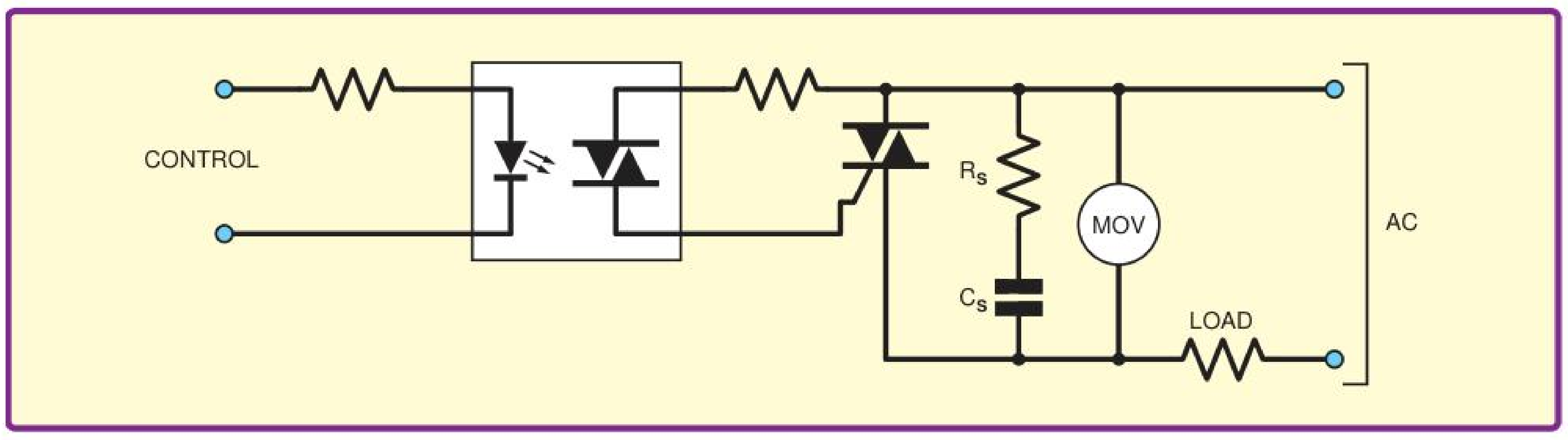

Fig.5. Triac circuit with snubber (R_s and C_s) to prevent false triggering and MOV for overvoltage protection

switch the triac at any point in the AC cycle. In fact 'random phase' may be a marketing phrase from Fairchild Semiconductor for devices in their FOD42XX series and some of their MOC30XX devices. It distinguishes these components from opto-isolators with built-in zero-crossing detection. Other manufactures use different terms – for example, Vishay simply use the phrase 'non-zero crossing' (eg, BRT1X family). Random phase, or non-zero crossing opto-isolators are required if the load is to be power controlled rather than simply switched.

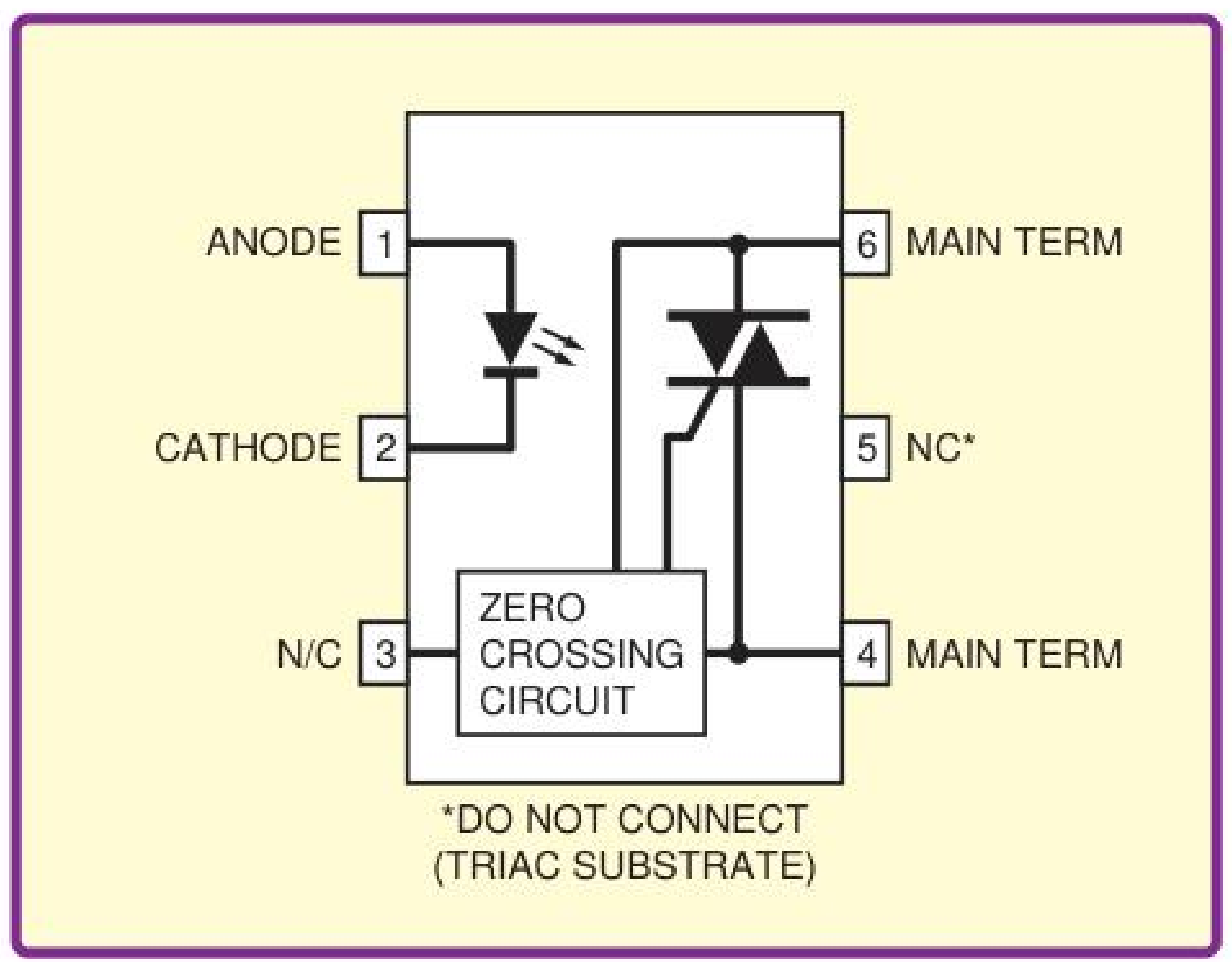

Fig.6. Opto-isolator with built in zero-crossing detection (eg, FOD410 from Fairchild Semiconductor)

Use of zero-crossing detection

Fig.6 shows the pinout of a typical zero-crossing opto-isolator for triac control, this is the FOD410 and related devices from Fairchild Semiconductor. Note that although the photo-sensitive device symbol looks like a triac it is not intended for direct switching of a load. This and similar devices are intended for triggering of power triacs. Use of zero-crossing detection means that the load is switch as the AC supply goes through zero volts. This reduces surge currents to the load and decreases the electromagnetic interference (EMI) caused by the load switching.

Fig.7 shows a typical application circuit using the FOD410 or similar, based on the Fairchild datasheet. As would also be the case for the circuits in Fig.3 and Fig.5, R_{in} is calculated using the control circuit supply voltage and LED forward current. The required forward current can be found by consulting the datasheet – it will be different for different devices, but typically in the order of milliamps. Typical snubber values are also shown, although the snubber may not be needed in all situations and for others different values will be required; again the datasheet will provide some guidance. The circuit shows the load in the neutral line, but it may also be on the live side.

Clearance and creepage

We have looked at a few examples of opto-isolated triac power switches; however, there is more to safe design of power switching than just including an opto-isolator in the schematic. For example, clearance and creepage must be considered when designing the circuit board. Clearance is the shortage path between the two conductive parts measured through air. For a given opto-isolator, the minimum clearance will probably be set by the device pins/PCB pads. Ideally, the layout should not take signals on the 'hot' and 'cold' sides any closer than this. Creepage is the shortage path between two conductive parts measured along the surface of the circuit board. Creepage is important because it is easy for the surface of a circuit board to become contaminated, which can significantly reduce the effective electrical isolation. Creepage is typically improved in an opto-isolated circuit by cutting a slot in the PCB underneath the opto-isolator between 'hot' and 'cold' sides. This significantly increases the creepage (but not the clearance).

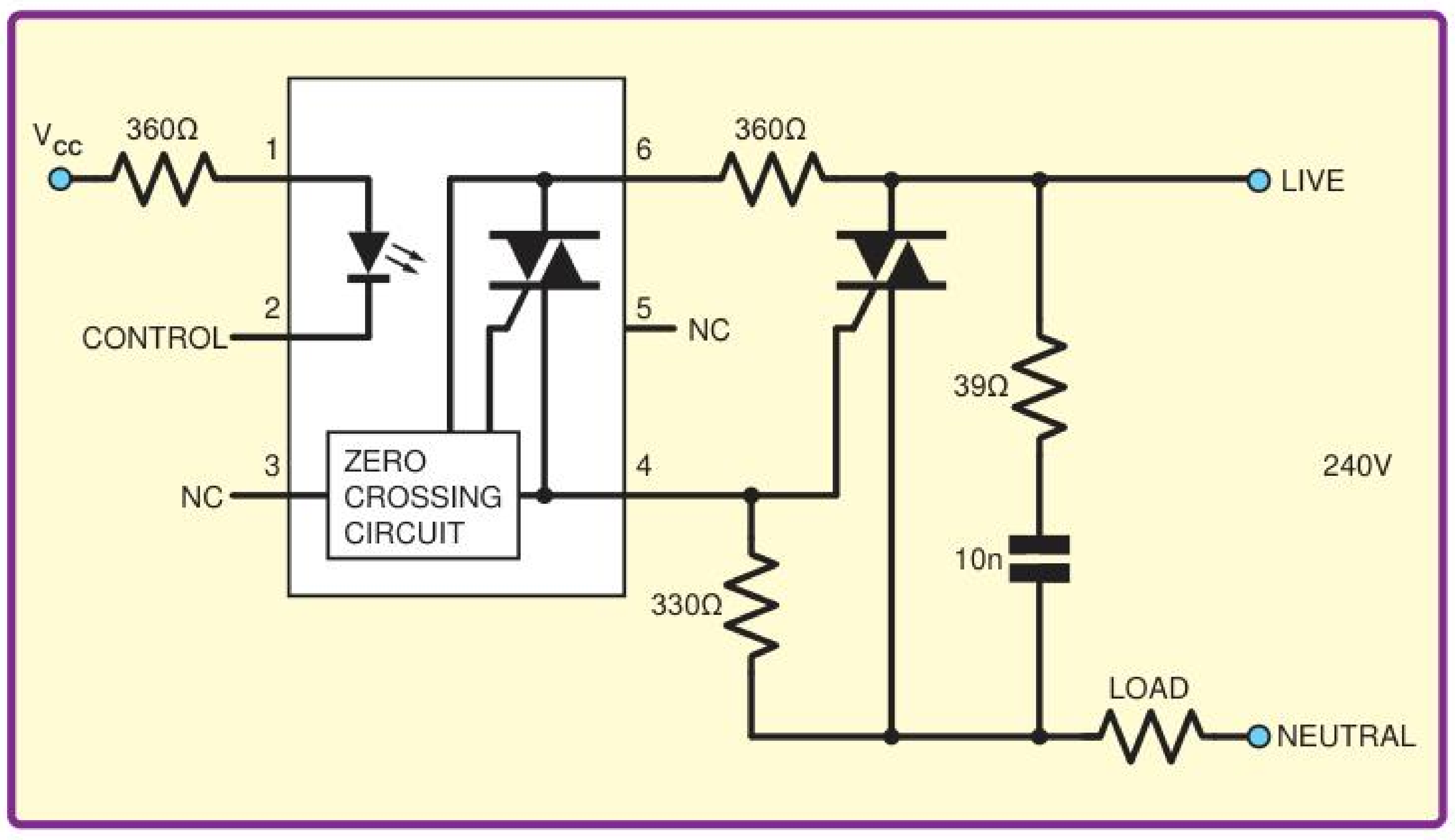

Fig.7. Typical zero-crossing opto-isolated triac power switching circuit, based on Fairchild Semiconductor FD410 datasheet. Component values may need to be different in real designs – please consult device datasheets

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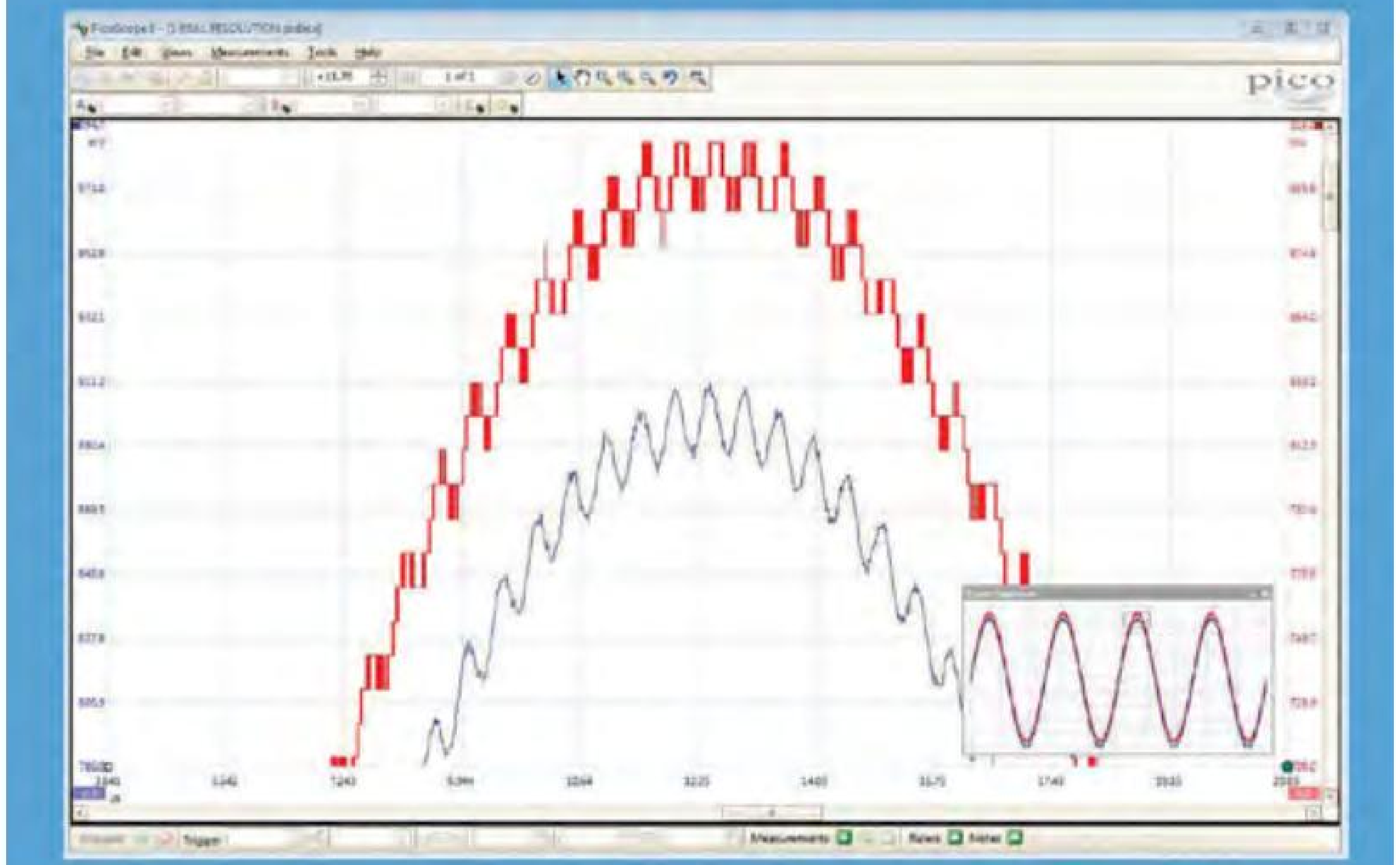

The top waveform in the screenshot, captured with 8 bits resolution and zoomed in by 64x shows up the limitations of 8-bit resolution. The same signal captured with PicoScope set to 12-bit resolution shows characteristics of the signal that were invisible in 8-bit mode. All selectable in the same scope.

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PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

Wrapping up the Development Board ADC

THE code for controlling the ADC peripheral that we introduced in last month's article looked simple enough, but it does mask a hidden problem – we have to poll for each conversion to complete. For many applications this is fine, but it will not offer the fastest conversion rate and for some applications speed is important. This month, we look to improve on the situation.

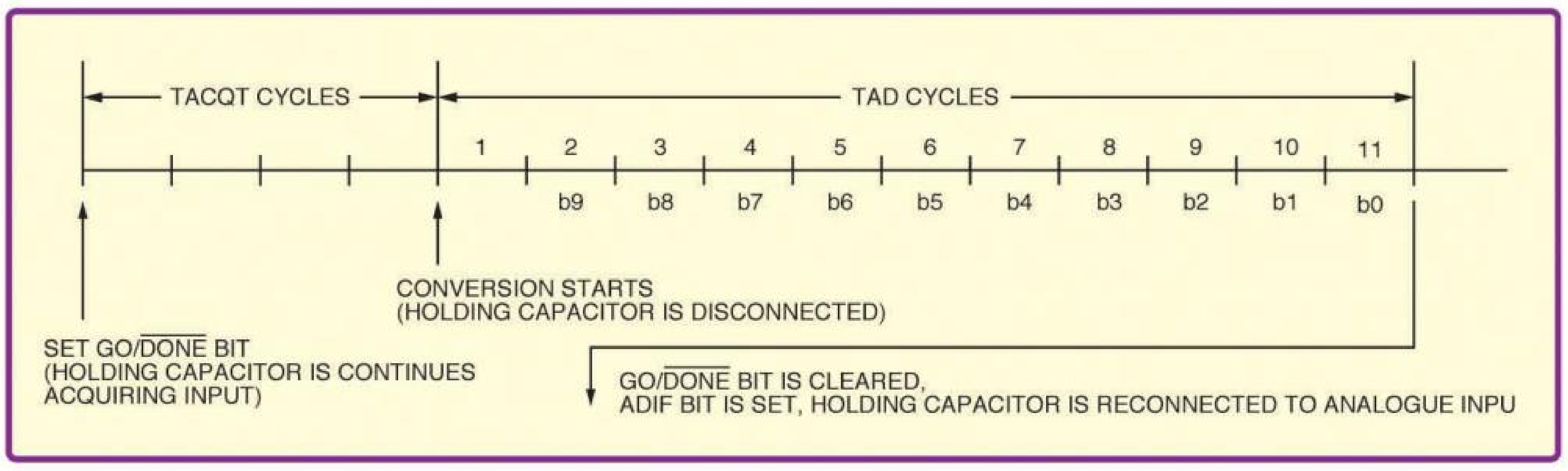

TACQT CYCLES
TAD CYCLES
1
2
3
4
5
6
7
8
9
10
11
b9
b8
b7
b6
b5
b4
b3
b2
b1
b0
CONVERSION STARTS
(HOLDING CAPACITOR IS DISCONNECTED)
SET GO/DONE BIT
(HOLDING CAPACITOR IS CONTINUES
ACQUIRING INPUT)
GO/DONE BIT IS CLEARED,
ADIF BIT IS SET, HOLDING CAPACITOR IS RECONNECTED TO ANALOGUE INPU

Fig.2. ADC operation

The API that we introduced for configuring and controlling the ADC peripheral is simple enough:

```
adc_int(param1, param2, param3, param4)

convert_adc(void)

busy_adc(void)

close_adc(void)
```

Using that API we start a conversion with `convert_adc()`, repeatedly call `busy_adc()` until it returns false and then read the data from the ADC value register (I've added a function called `getval_adc()` to make that a bit more general purpose and less CPU specific.) However, before we get into the improvements to our design, let's take a look at the ADC in more detail.

Under the hood

Fig.1 shows the basic principle behind the operation of the ADC. An input pin (configured to be an analogue input) is connected via a switch to a 25pF capacitor. There are many pins that can be analogue inputs and missing from this diagram is a multiplexer (to the left of the switch) which would direct the appropriate input to the ADC circuit.

The ADC peripheral has a simple 'state machine', a series of operations that it follows. When the GO/DONE bit is set the first operation that occurs is that the switch is closed to connect the input to the capacitor. After a predetermined period of time – `TACQT` – the switch is opened and the conversion started. A predetermined delay – `TAD` – is applied for each data bit to be evaluated. Once all ten bits have been evaluated, the result is copied into the ADRES register. As the ADC is ten bits wide, there are two registers required to hold this value: ADRESH (for the two most significant bits) and ADRESL, for the lower eight bits.)

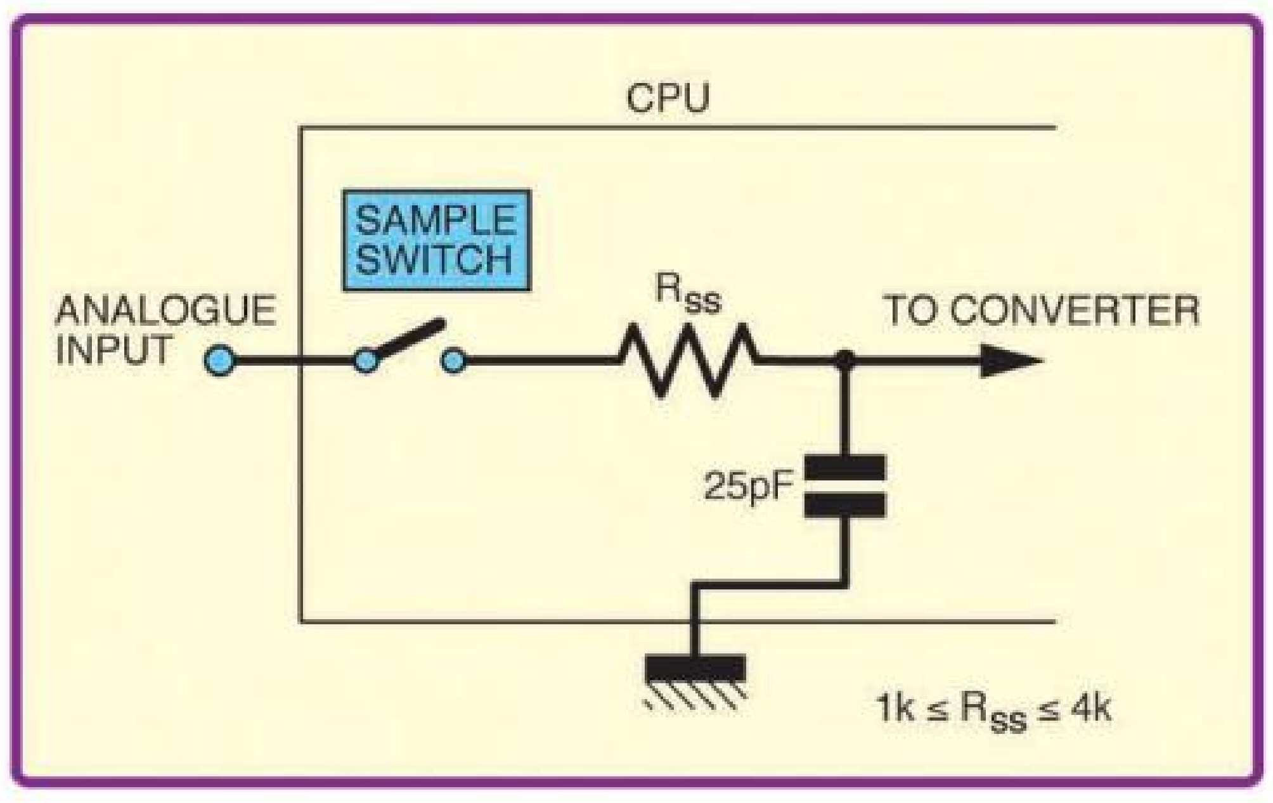


Fig.1. Basic ADC input circuit

`TACQT` and `TAD` are timing parameters that we control, and we can already see that the time taken for each sample is going to be

```
TACQT + (11 * TAD)
```

Yes, it's actually 11 `TAD` periods rather than 10. The extra `TAD` time is the time for the final bit conversion.

The progression of the ADC state machine can been seen in Fig.2. The `TACQT` time period can be programmed as a multiple of the `TAD` period or left at its power-on default value of zero. In this case, the input signal is continuously sampled until the GO/DONE bit is set by calling `convert_adc()`.

This may sound like the 'normal' operating mode, but it is much more convenient to calculate the minimum required acquisition time and program the ADC peripheral to handle the entire process itself. It's possible to configure a periodic timer to trigger the start of ADC conversion, and coupled with an interrupt fired when the conversion completes, you can automate continuous ADC sampling in the background with a tiny bit of interrupt code.

Fully automating the ADC conversion is a topic for another day, but we will look at support for picking up the end of conversion in an interrupt to avoid wasting time (and CPU cycles that should be doing something more productive) in a loop waiting for the GO/DONE bit to clear. Or perhaps put the processor into a lower power operation mode.

Software operation

The process for managing the ADC converter 'under the hood' of our API interface is:

1) Configure the input source, ADC options, ADC clock speed

2) Set GO/DONE

3) Wait for GO/DONE to be cleared

4) Read value from ADRESH/L

5) Repeat from 2) if desired.

The inefficiency with the current design is step 3, where we wait for the conversion to complete. Thankfully, we can configure the processor to generate an interrupt at this point. Inside the interrupt routine we can read the ADC value from ADRESH/L, store it somewhere, set a variable to tell the main program that a value has been received, and restart the conversion. The values could even be stored in a buffer to allow multiple samples to be stored before the main application gets time to read the values, but typically we just make the latest sample available.

Enabling the interrupt is easy; we simply clear the ADIF bit in the PIR1 register, and set the ADIE bit in the PIE1 register. We wrap this simple sequence of code in an API function `int_enable_adc()`. At the same time, we updated the `close_adc()` API function to clear these two bits, so we properly tidy up the module when we've finished with it. In most embedded systems one would never need to turn off an enabled module – it would typically be required all the time – but sometimes it comes in handy.

Don't forget that to use these functions the global interrupt enable bit PEIE and GIE in the INTCON register must be set. We don't enable them in the ADC routines as they will almost certainly be used by other interfaces. Your main application will need to decide when to enable those two bits. Our template code already enables them in the main function.

Interrupts

Handling the interrupt is more complicated, as we need to know the Microchip-compiler-specific syntax for connecting a C function to the hardware interrupt. Fortunately, the basics of this have already been provided in the template code, in the file **interrupts.c**. We have to integrate our ADC handler into this function however, as it currently handles just the timer interrupt. At the moment, the code looks like:

```
void interrupt InterruptHandler( void )

{

// Clear the interrupt flag. Only one interrupt is enabled,

// so this must be it

PIR1bits.TMR1IF = 0;

...
```

We need to improve this now to test for any number of interrupt sources, starting with our ADC interrupt. The simplest way is with an `if` statement:

```
void interrupt InterruptHandler( void )

{

// Find which interrupt occurred

if (PIR1bits.TMR1IF) {

PIR1bits.TMR1IF = 0;

} else if (PIR1bits.ADIF) {

PIR1bits.ADIF = 0;

handle_int_adc();

}
```

From now on, additional interrupt sources can be handled by adding further `else if` statements.

Notice how we call a routine named `handle_int_adc`. This code is in the **adc.c** file, and does the actual work of handling the interrupt. This 'call' to a routine adds a few microseconds to the time required to handle the interrupt, but it makes the code better organised – the 'detail' of what that interrupt does should be localised to the **adc.c file**; the **interrupt.c** file should, and does, focus on interrupt processing only.

You may be asking 'but what if two interrupts are activated at the same time?' After the first interrupt is handled, the main interrupt routine is exited. The processor, however, notices that an interrupt flag is still active and will immediately re-invoke the main interrupt routine.

Calculating the TACQT and TAD times

Referring to the datasheet, snippets of fragmented text explain the various delays required and minimum settings for TACQT and TAD.

First, the value of TACQT needs to be calculated, and this will be depend on the output impedance of your input signal source and the supply voltage and temperature of the chip. (There is an equation for this on page 374 of the datasheet.) Taking as a reasonable example an input impedance of 2.5kΩ, a supply voltage of 3V and a chip temperature of 85ºC, we need to allow 2.45µs for the capacitor to charge.

Next, we need to determine the value of TAD. This is actually dependant on the oscillator clock speed and the ADC input divisor, but we should aim to set it to as short a time as possible, but no shorter than 0.7µs. Setting it too long will result in the natural decay of charge on the sample capacitor, affecting the accuracy of our results.

Going back to our equation for total conversion time, this gives us a time of:

2.45µs + (11 × 0.7µs) or 10.15µs.

That equates to a sampling frequency of 98kHz. This is a maximum theoretical limit and our real sample rate will be limited by our choice of processor oscillator frequency and how fast we can process the data in our main application – *much* slower if we are running a Fourier transform algorithm, for example.

The template code has been updated and an interrupt version of the potentiometer code added. You can download the update from the usual location on the magazine website.

The ADC setup routine has been enhanced to include the setting of TACQT, to accommodate different input impedances. Our example circuit from last month for example has a 24k input impedance (worst case, it's a 47k trimpot) and so would require a 6µs TACQT value rather than 2.45µs.

What can we do with the ADC peripheral, besides reading a potentiometer? A really great use is to measure the internal reference voltage source of the processor so you can determine the supply voltage (perfect for battery-powered applications.) You may also run a fast Fourier transform (FFT) algorithm to identify the power levels of different frequencies in your input, ideal for monitoring mechanical wear in moving systems, or analysing sound signals.

Next month

Next month, we'll add pulse-width modulation (PWM) control to our template library, and examine the difference between a home-grown 'bit-bashed' solution and the on-chip peripheral.

LPLC TOO Kickstarter update

My second Kickstarter project was a success – many thanks to all of you who supported this. The board, shown in Fig.3, is a *very* tiny version of the LPLC development board. It's aimed at wearable computing and 'Internet of Things' applications, where you need a very small and low-power computing platform to join a sensor to a transmitter, transceiver or a few LEDs. With the backing of people through Kickstarter, I have been able to secure volume manufacturing in China. By the time you read this the boards should have been delivered to backers, and will be available for purchase on **mjhdesigns.com**.

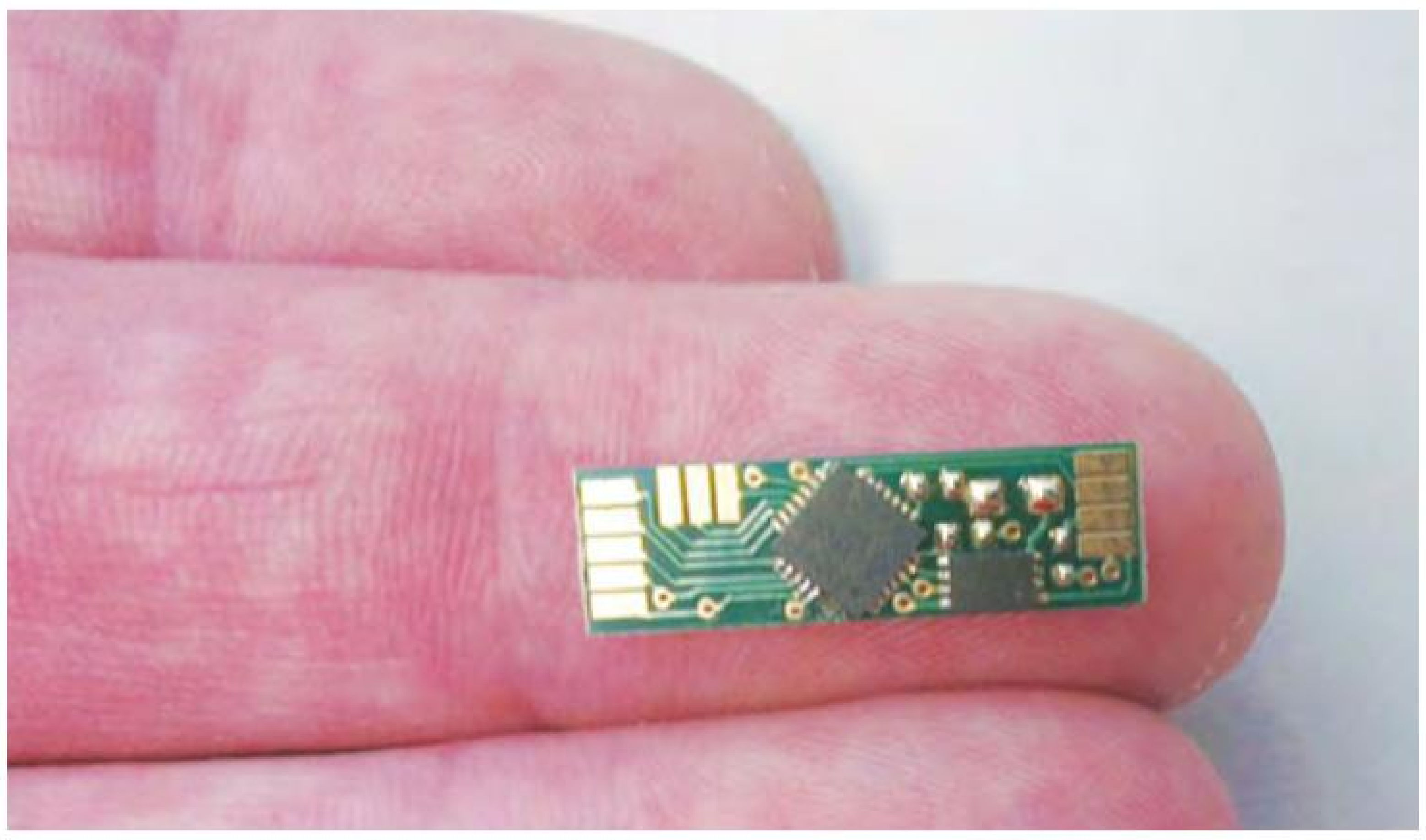


Fig.3. LPLC TOO – the tiny LPLC board

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at ***@MikeHibbett****, and from his blog at* ***mjhdesigns.com***

Max's Cool Beans

By Max The Magnificent

Mastering meters

In the not-so-distant past, the majority of electromechanical displays were analogue in nature – for example, a bedside clock. More recently, digital displays have taken center stage. There are some who will say that digital displays are more accurate than their analogue counterparts, but the accuracy of data being displayed depends not only on the display mechanism, but also on the way in which the data is gathered and processed.

Some people will also say that digital displays are quicker and easier to read than their analogue cousins, but this is not always the case. A simple glance at an analogue meter will tell you if its needle (pointer) is in the safe, warning, or danger zones.

Apart from anything else, I like using analogue meters for my hobby projects because they offer a certain sense of style. And as I mentioned in a previous column, one of my current projects is to create a Vetinari Clock using a large meter to represent the hours from 1 to 12; two medium-sized meters to display the minutes and seconds, both from 1 to 60; and a small meter swinging back and forth like a mini-metronome ticking off the seconds.

Now, some people may prefer to use brand spanking new analogue meters for their projects; others, like me, favour antique offerings from yesteryear. These vintage beauties can be tracked down at electronic flea markets, rescued from old equipment, or acquired on the Internet. Once you have one of these 'old timers' in your possession, the next trick is to control it using a microcontroller, which for the purpose of these discussions we will assume means using an Arduino Uno with a 5V power supply.

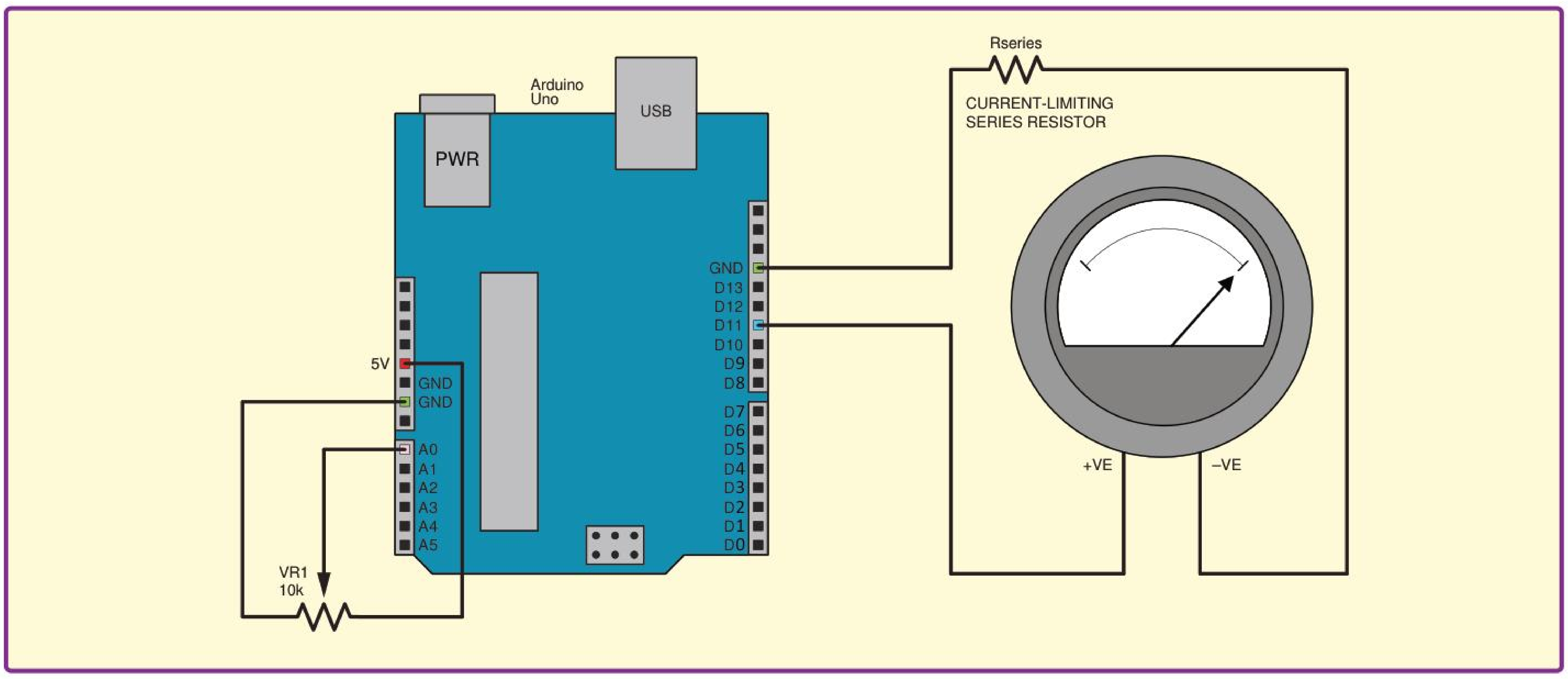
New and old meters

Let's start by considering new meters (as we will see, there is a world of difference working with new meters as opposed to the older kind). If you are purchasing a new meter, make sure it's designed for measuring DC (not AC) current (not voltage). It's also a good idea to work with a more sensitive meter (like a 50µA unit) rather than a less sensitive version (for example, a 100mA device). In this context, we can consider the term 'sensitivity' to refer to the amount of current required to achieve full-scale deflection (FSD) of the needle. Thus, a 50µA meter is more (20 times) sensitive than a 1mA meter, for example.

Driving your meter

In the fullness of time, we will want to display data on our meter(s). This data may be generated algorithmically by software, or it may reflect the state of a sensor. But before we reach that point, we need to ensure that we can control our meter. Consider the circuit and associated Arduino code shown below. This is the 'cheap and cheerful' setup in which we are driving the meter directly from an Arduino pin using pulse-width modulation (PWM). In this case, you should not drive a meter with a sensitivity of more than 20mA (we'll consider driving larger meters in my next column).

Don't connect your meter yet (our program will run perfectly well without the meter). Let's start by connecting potentiometer VRI and running our program. If you open the serial monitor on your host computer, you will see the value associated with the current position (rotation) of the potentiometer. When you rotate the pot from one extreme to the other, the value should vary between 0 and 255. Important – do note that the



How to control a new-style current-driven analogue meter using an Arduino Uno value read on the Arduino's analogue input A0 actually ranges from 0 to 1,024, but our code uses the `map()` function to scale this down to the 0 to 255 value we will need later on.

I prefer a set-up where turning the pot clockwise causes the value to increase – that's just the way I think. If you agree with me, but your setup is working the opposite way, simply swap the 5V and GND connections to the pot and all will be well.

Resistance is futile! (or unknown)

OK, let's assume we are working with a 50µA (0.00005A) meter. This meter will have an internal resistance we might call `Rcoil`. Now, using Ohm's law, we can calculate the total resistance, `Rtotal`, using `V = I x Rtotal`. So `Rtotal = 5V/0.00005A = 100kΩ`. Furthermore, we know that `Rtotal = Rcoil + Rseries`, which means `Rseries = Rtotal – Rcoil`. 'Well, that's easy-peasy,' I can hear you say. There's just one teeny-weenie little fly in the soup… we typically don't know the value of `Rcoil`.

'Ah, ha,' you say, let's use our trusty multimeter to determine this nugget on knowledge. No! Put that multimeter down! Some of these meters are so sensitive that you can burn out the coil using a multimeter to try to measure the resistance.

Obviously it seems as though we're on a sticky wicket, but there is a solution, which is to pretend that `Rcoil` is insignificant in the scheme of things. Let's start with this assumption. In this case, and remembering we're assuming a 50µA meter, we want an `Rseries` resistor of 100kΩ as discussed above. I typically work with 5% tolerance resistors (the E24 series), and there is indeed a 100kΩ value available. The problem is the 5% tolerance, which means our resistor could actually be anywhere between 95kΩ and 105kΩ. If our total resistance `Rtotal` exceeds 100kΩ, then our meter will never achieve full scale deflection. The next value down in the E24 series is 91kΩ, so this is what we'll use.

As an aside, although we don't know the exact `Rcoil` value, it can be as high as 3.5kΩ for a 50µA meter (the coil is formed from very many turns of very fine wire). But 91kΩ + 3.5kΩ = 94.5kΩ, which is comfortably below our 100kΩ maximum.

Listing

```
#define inPotPin     0
#define outMeterPin 11

int inPotVal;

void setup() {

  Serial.begin(9600);
}

void loop() {
  inPotVal = analogRead(inPotPin);
  inPotVal = map(inPotVal,0,1023,0,255);

  Serial.print("inPotVal = ");
  Serial.println(inPotVal);

  digitalWrite(outMeterPin,inPotVal);

  delay(100);
}
```

Calibration for FSD

OK, now we connect up the meter and our `Rseries` resistor as shown in the circuit. Note that a new meter will have a '+' symbol associated with one of its terminals (you can't guarantee this with older meters). Turn the potentiometer anticlockwise to its zero value and then power everything up. Slowly (and I mean slowly) turn the potentiometer clockwise and observe the meter needle start to move.

This is important. We know our actual `Rtotal` value is less than the `Rtotal` value we calculated. This means that if we drive the PWM output with its full value of 255, our poor old meter will be jammed hard up against its end-stop and we could actually damage the poor little scamp.

Continue to slowly turn the pot until the needle just reaches its FSD. Now observe the value of the pot being displayed in your serial monitor window. Let's assume that this value is 238. This means that the maximum value we wish to drive out of the PWM output is 238, so let's go back to our program and change the call to the `map(0)` function to read as follows:

```
inPotVal = map(inPotVal,0,1023,0,238);
```

Upload this new program into the Arduino. Now, rotating the potentiometer fully clockwise will cause the meter to just achieve its FSD.

As I said, the above solution is the 'cheap and cheerful' version because it requires only a single resistor. The problem is, by remapping everything to a smaller range of PWM values, we've sacrificed some resolution. A better option would be to replace `Rseries` in the diagram above with a standard resistor of value 2/3 `Rtotal` in series with a multi-turn (I like 25-turns) trimmer potentiometer of value 2/3 `Rtotal` (rounded to the nearest available values, of course).

In this case, we keep our original mapping of 0 to 255 in our `map()` function. We set our trimmer potentiometer to its maximum value, apply power, turn VR1 fully clockwise such that our PWM output is driving a value of 255 into the meter, and then gradually adjust the trimmer potentiometer until the meter's needle just achieves its full-scale deflection.

Next month

In my next column, we'll consider how you set about using antique analogue meters from the days of yore. Working with these can be significantly more demanding, but the resulting look and feel will be much more impressive. Until next time, have a good one!

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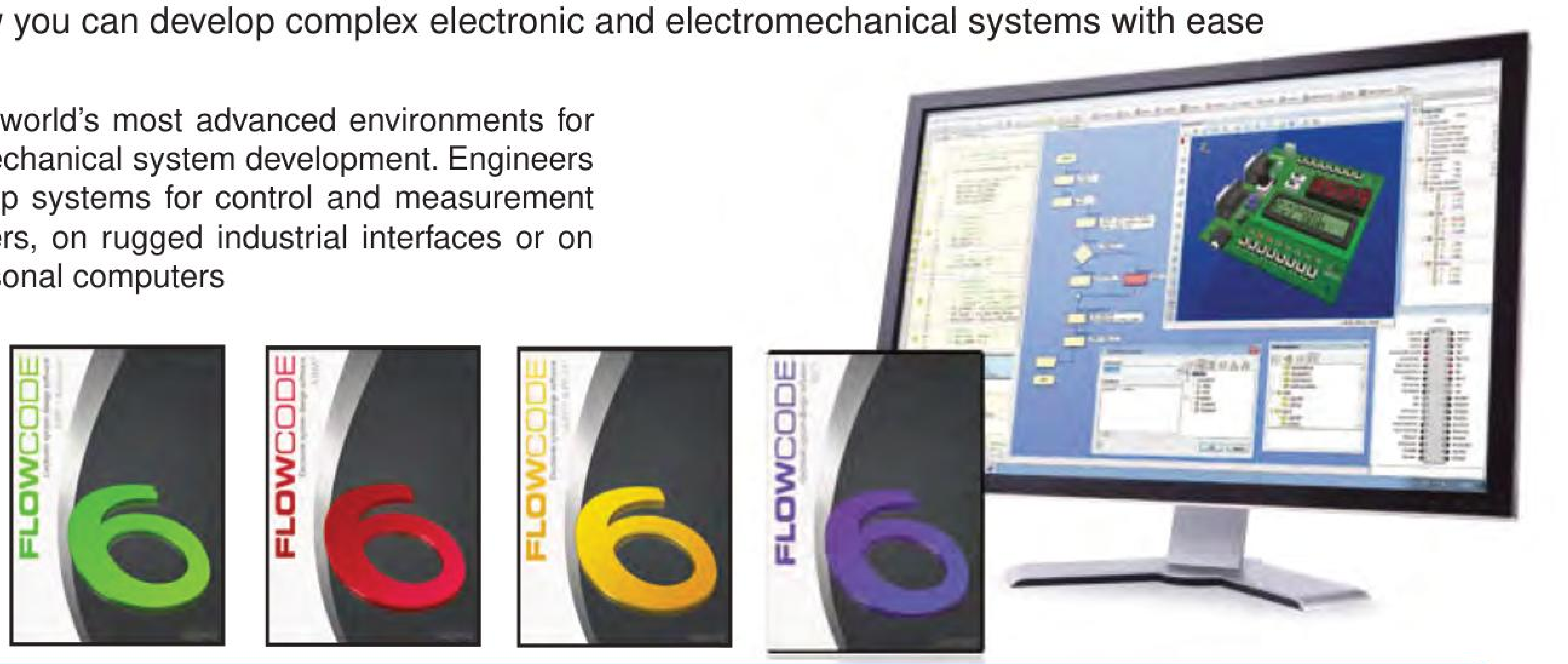

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value read on the Arduino's analogue input A0 actually ranges from 0 to 1,024, but our code uses the `map()` function to scale this down to the 0 to 255 value we will need later on.

I prefer a set-up where turning the pot clockwise causes the value to increase – that's just the way I think. If you agree with me, but your setup is working the opposite way, simply swap the 5V and GND connections to the pot and all will be well.

Resistance is futile! (or unknown)

OK, let's assume we are working with a 50µA (0.00005A) meter. This meter will have an internal resistance we might call `Rcoil`. Now, using Ohm's law, we can calculate the total resistance, `Rtotal`, using `V = I x Rtotal`. So `Rtotal = 5V/0.00005A = 100kΩ`. Furthermore, we know that `Rtotal = Rcoil + Rseries`, which means `Rseries = Rtotal – Rcoil`. 'Well, that's easy-peasy,' I can hear you say. There's just one teeny-weenie little fly in the soup… we typically don't know the value of `Rcoil`.

'Ah, ha,' you say, let's use our trusty multimeter to determine this nugget on knowledge. No! Put that multimeter down! Some of these meters are so sensitive that you can burn out the coil using a multimeter to try to measure the resistance.

Obviously it seems as though we're on a sticky wicket, but there is a solution, which is to pretend that `Rcoil` is insignificant in the scheme of things. Let's start with this assumption. In this case, and remembering we're assuming a 50µA meter, we want an `Rseries` resistor of 100kΩ as discussed above. I typically work with 5% tolerance resistors (the E24 series), and there is indeed a 100kΩ value available. The problem is the 5% tolerance, which means our resistor could actually be anywhere between 95kΩ and 105kΩ. If our total resistance `Rtotal` exceeds 100kΩ, then our meter will never achieve full scale deflection. The next value down in the E24 series is 91kΩ, so this is what we'll use.

As an aside, although we don't know the exact `Rcoil` value, it can be as high as 3.5kΩ for a 50µA meter (the coil is formed from very many turns of very fine wire). But 91kΩ + 3.5kΩ = 94.5kΩ, which is comfortably below our 100kΩ maximum.

Listing

```
#define inPotPin     0
#define outMeterPin 11

int inPotVal;

void setup() {

  Serial.begin(9600);
}

void loop() {
  inPotVal = analogRead(inPotPin);
  inPotVal = map(inPotVal,0,1023,0,255);

  Serial.print("inPotVal = ");
  Serial.println(inPotVal);

  digitalWrite(outMeterPin,inPotVal);

  delay(100);
}
```

Calibration for FSD

OK, now we connect up the meter and our `Rseries` resistor as shown in the circuit. Note that a new meter will have a '+' symbol associated with one of its terminals (you can't guarantee this with older meters). Turn the potentiometer anticlockwise to its zero value and then power everything up. Slowly (and I mean slowly) turn the potentiometer clockwise and observe the meter needle start to move.

This is important. We know our actual `Rtotal` value is less than the `Rtotal` value we calculated. This means that if we drive the PWM output with its full value of 255, our poor old meter will be jammed hard up against its end-stop and we could actually damage the poor little scamp.

Continue to slowly turn the pot until the needle just reaches its FSD. Now observe the value of the pot being displayed in your serial monitor window. Let's assume that this value is 238. This means that the maximum value we wish to drive out of the PWM output is 238, so let's go back to our program and change the call to the `map(0)` function to read as follows:

```
inPotVal = map(inPotVal,0,1023,0,238);
```

Upload this new program into the Arduino. Now, rotating the potentiometer fully clockwise will cause the meter to just achieve its FSD.

As I said, the above solution is the 'cheap and cheerful' version because it requires only a single resistor. The problem is, by remapping everything to a smaller range of PWM values, we've sacrificed some resolution. A better option would be to replace `Rseries` in the diagram above with a standard resistor of value 2/3 `Rtotal` in series with a multi-turn (I like 25-turns) trimmer potentiometer of value 2/3 `Rtotal` (rounded to the nearest available values, of course).

In this case, we keep our original mapping of 0 to 255 in our `map()` function. We set our trimmer potentiometer to its maximum value, apply power, turn VR1 fully clockwise such that our PWM output is driving a value of 255 into the meter, and then gradually adjust the trimmer potentiometer until the meter's needle just achieves its full-scale deflection.

Next month

In my next column, we'll consider how you set about using antique analogue meters from the days of yore. Working with these can be significantly more demanding, but the resulting look and feel will be much more impressive. Until next time, have a good one!

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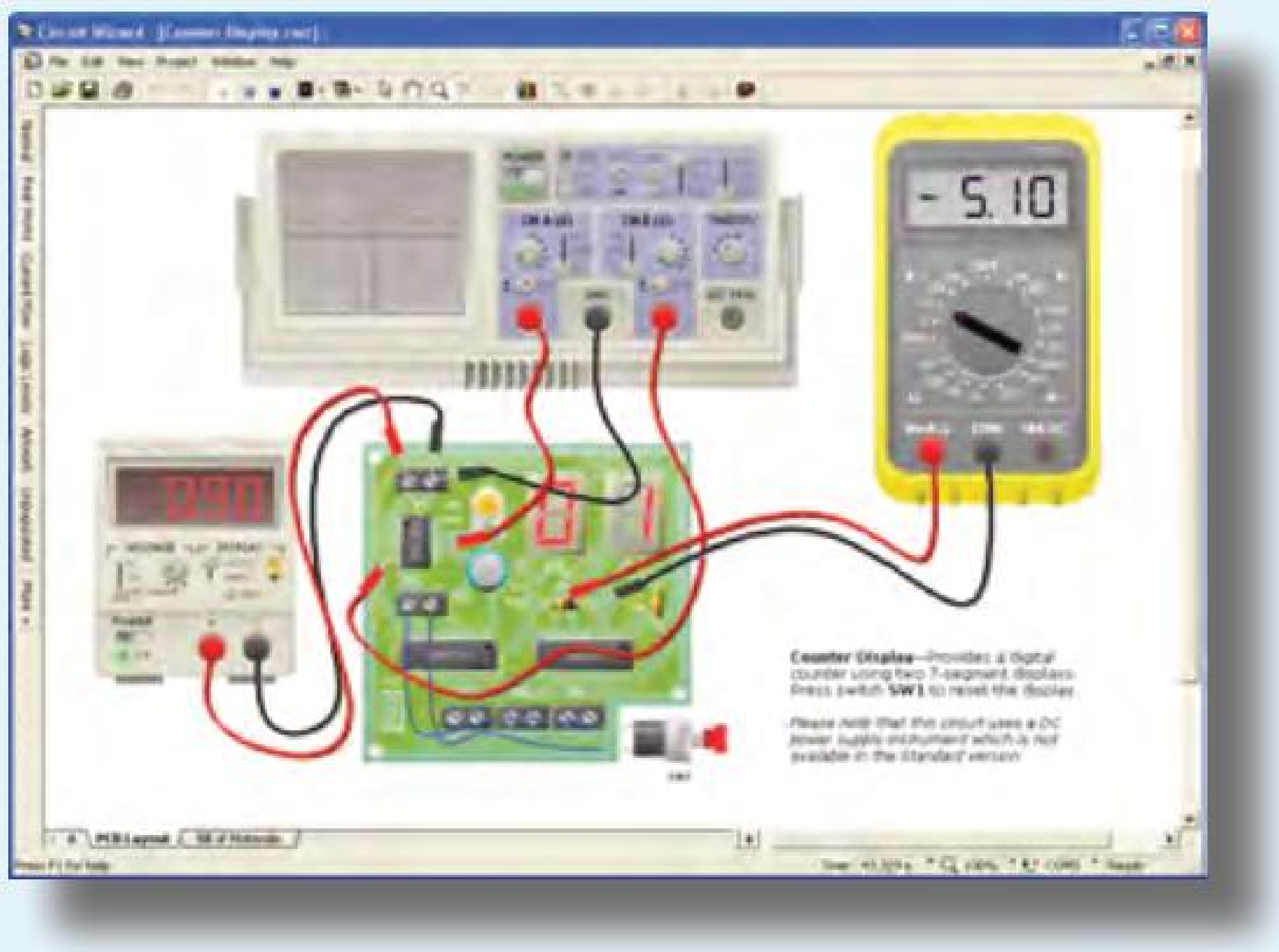

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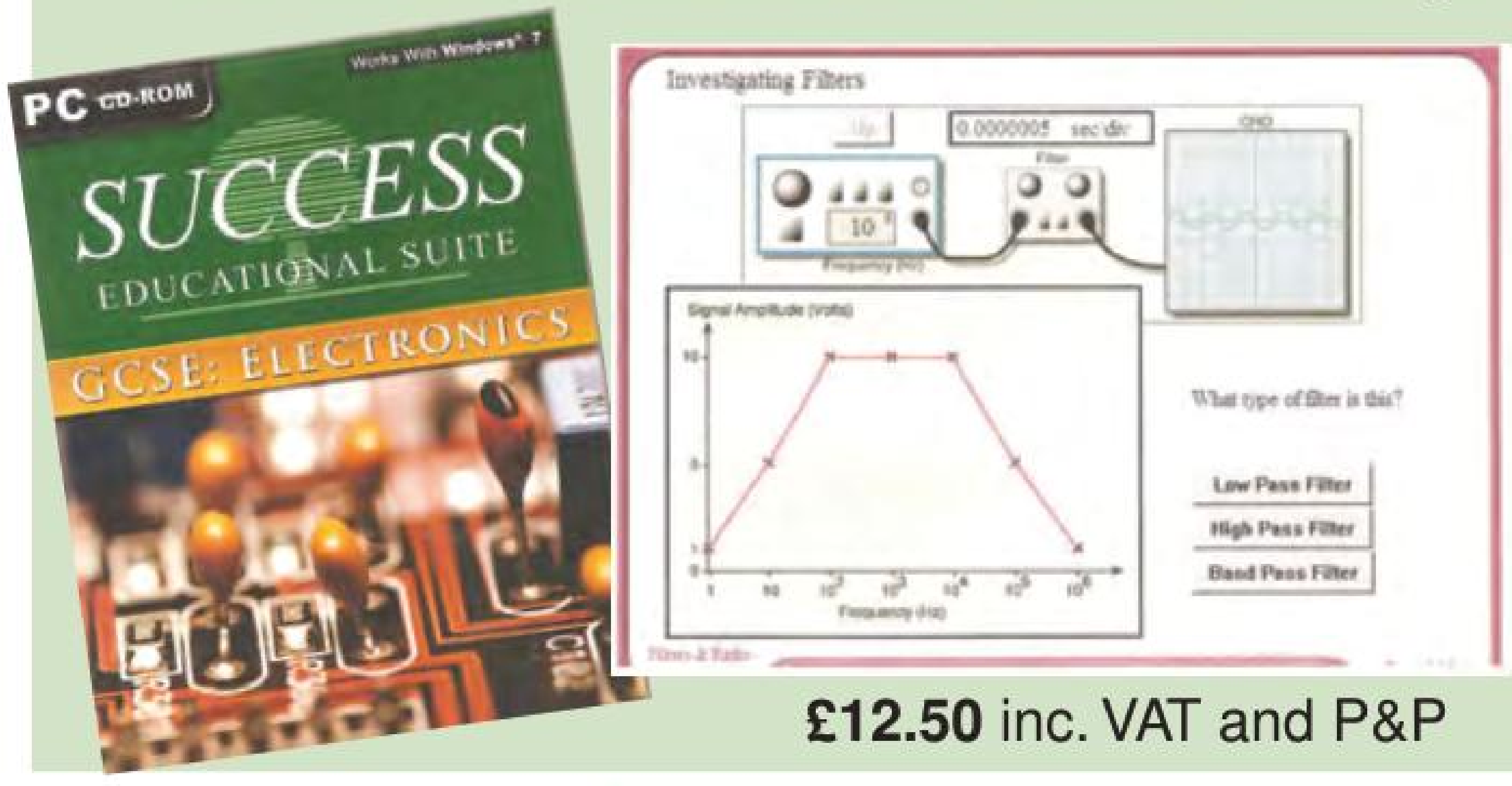

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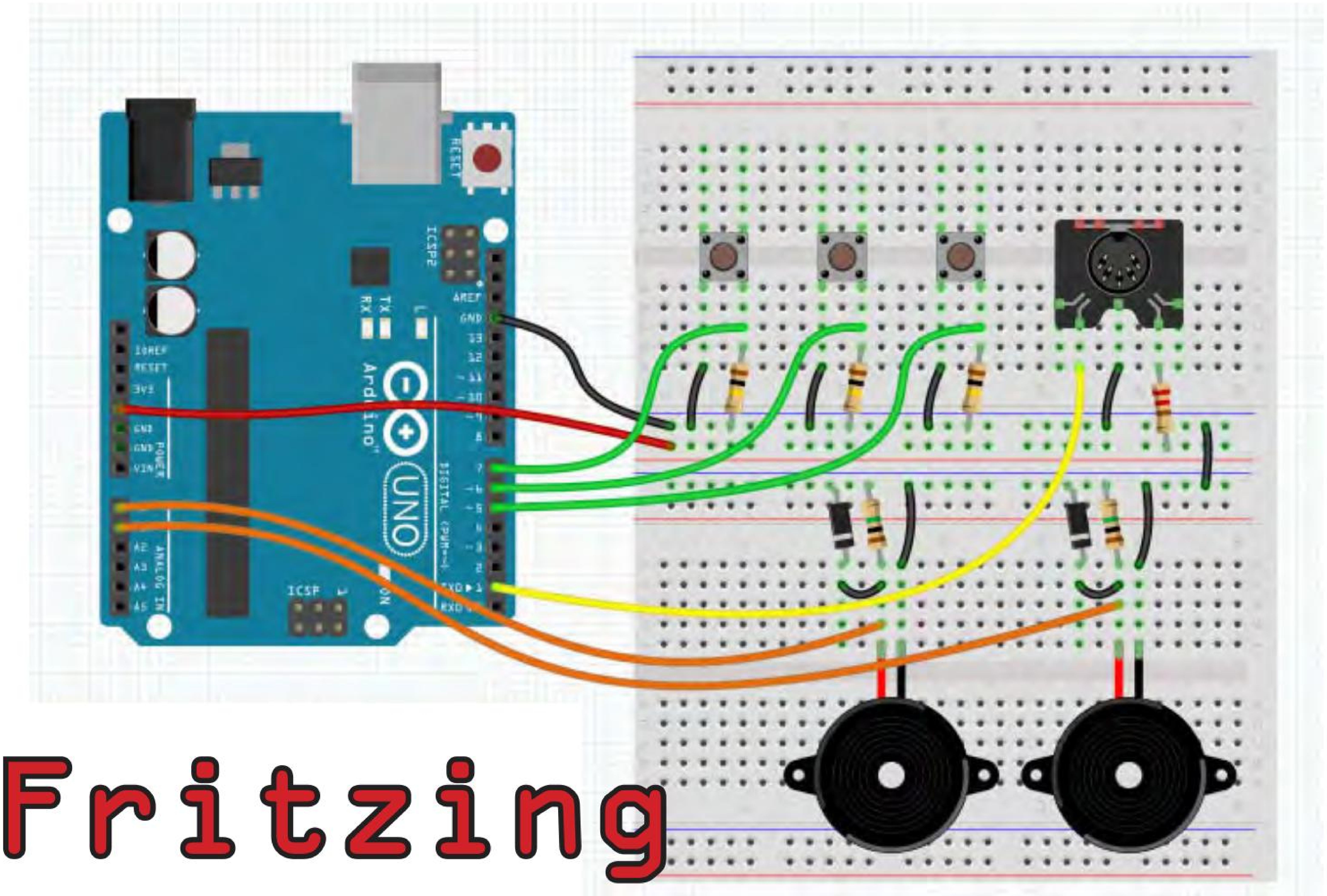


Fritzing Design Software

Mike Hibbett takes a look at 'Fritzing', a powerful but easy-to-use electronics design package that's popular with the 'Maker' community.

Maker CAD

While researching the *Making your own PCBs* article series (*EPE*, Sep – Dec 2014) I came across an interesting application called 'Fritzing', an electronics and PCB design tool with a rather unusual user interface. Initially developed by researchers in Potsdam, Germany and released as an open source program, it has become very popular among the hobbyist community. You can see why when you look at the user interface, in Fig.1 and Fig.3.

Fritzing has a very intuitive user interface, displaying components with lifelike images rather than abstract symbols. Links to tutorials, videos and user forums are displayed on the front page, making it easy to find help, explore other people's designs and join in the community. This is a popular program within the 'Maker' community – evident from the half-million hits for the word 'Fritzing' on Google. The forums are active and the user community has released hundreds of designs for people to try.

Open source for hobbyists

The release of the program as open source is significant, it means you have free access to the source code, and can make changes if you wish. While this is not a practical solution for most people, the software development process is public, and the designers do listen to requests for changes. Development is driven by the desire to improve the program, not to make more money, which would be the main motivation for a commercial development.

A non-profit group has been created to organise the further development of the program and provide a focus for requests and donations to the project. The program runs under Microsoft Windows, Apple OSX and Linux.

Fritzing is not designed to compete with normal CAD tools such as EagleCAD or DesignSpark; it's designed for hobbyists and those relatively in-experienced with electronics. Unlike traditional CAD programs that make use of abstract symbols and notations, Fritzing uses (whenever possible) lifelike images. It is also biased towards the 'Maker' approach to electronics, where a project consists of one or more electronic modules wired together with a few additional components.

In comparison to normal CAD programs, Fritzing is easy to use, although not trivial – it's a powerful program with many features and you do have to have some knowledge and experience with electronics. That can be gained through experimentation, chatting to people on the friendly web forums or by watching the wide range of video tutorials covering the use of the tool itself and electronics in general.

While it may not be simple to use at first, it is enormous fun, right from the start. Components, wires, modules and breadboard images look like the real things, and creating a

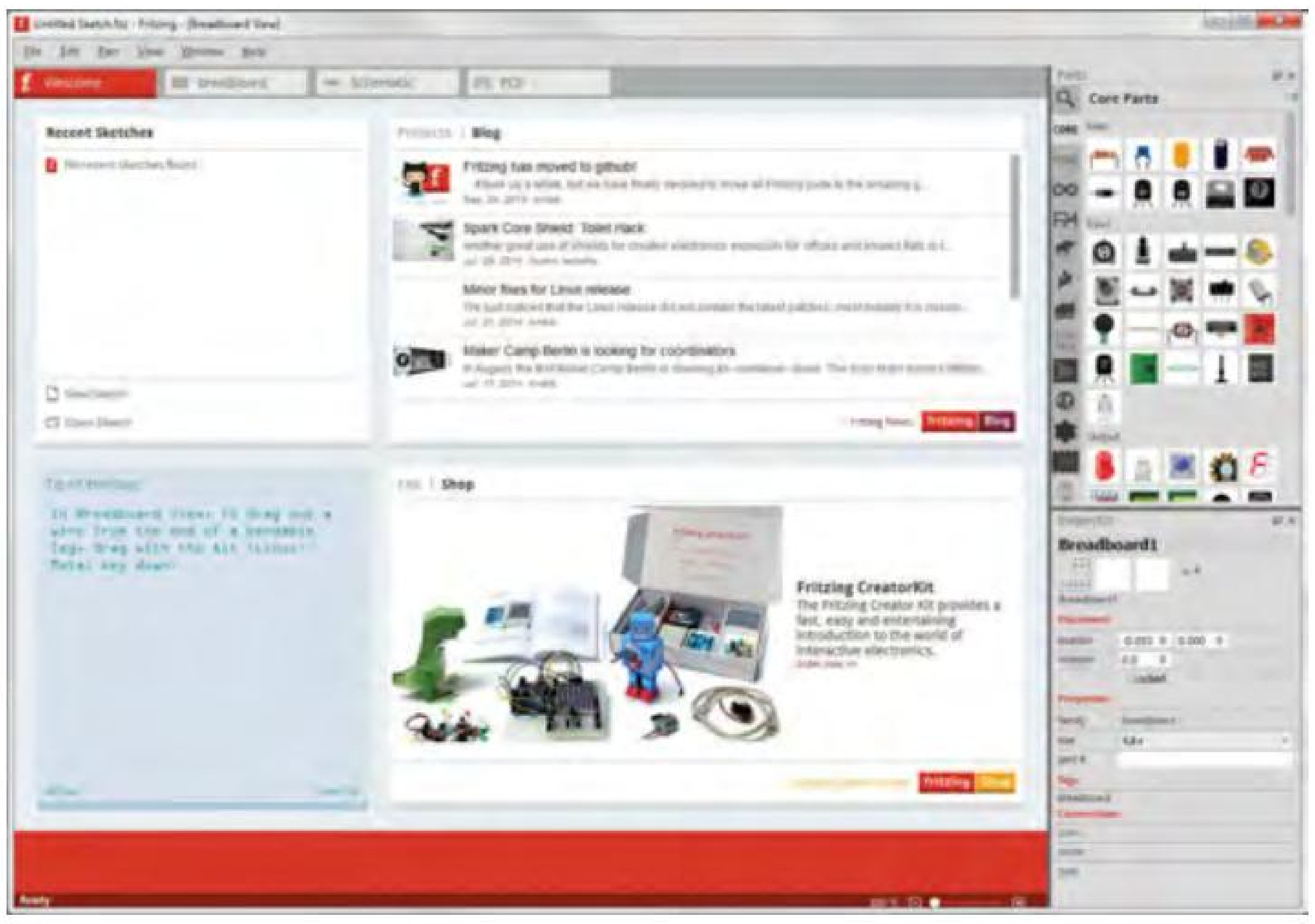


Fig.1. The Fritzing application start-up screen

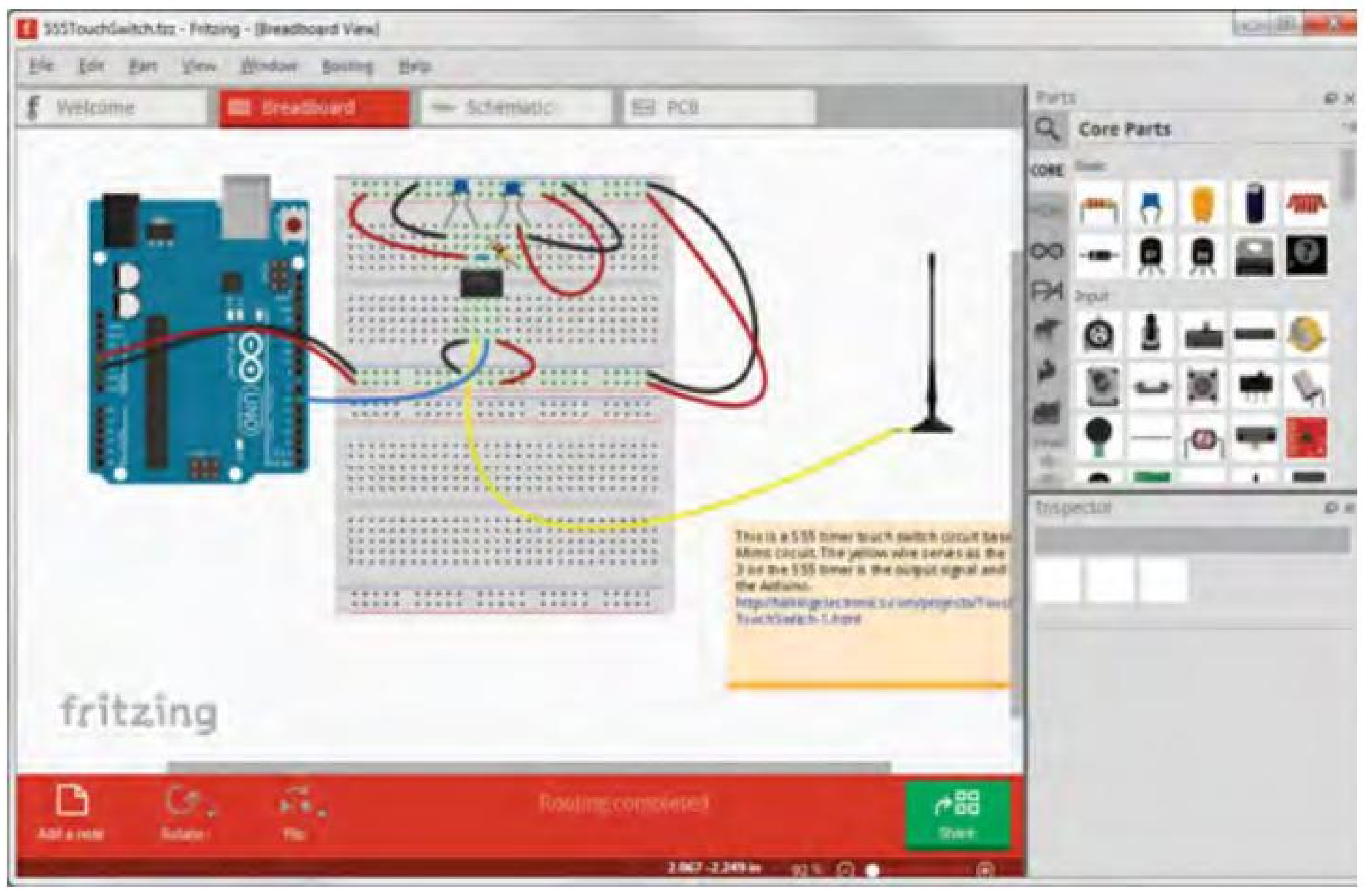


Fig.3. One of the many sample projects

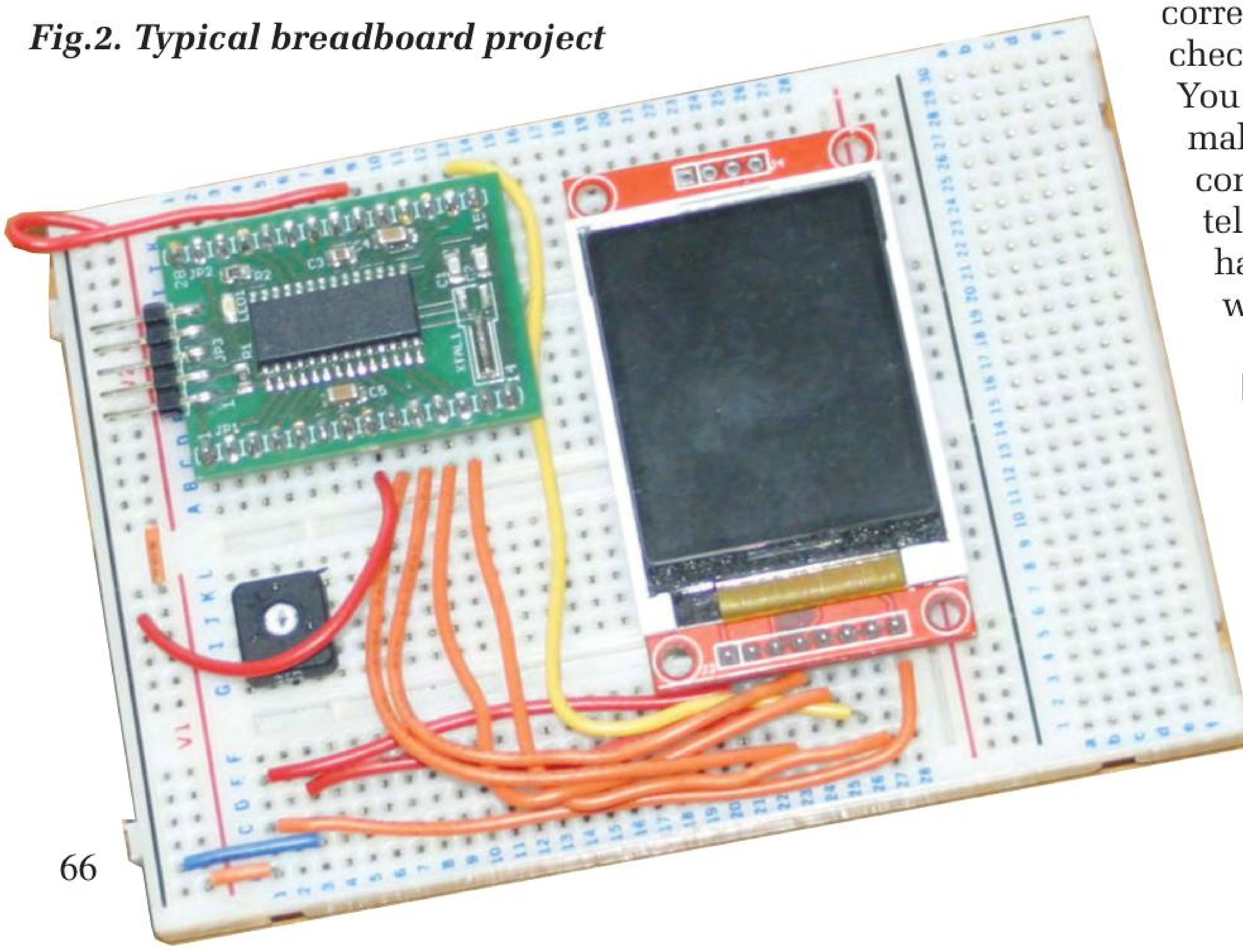
circuit by dragging these items around the screen is about as lifelike as it is going to get in a virtual design environment. You really feel like you are making something with physical components, and it helps you identify with what you are creating. Traditional CAD programs display the circuit in a more abstract manner, making the schematic entry more efficient but far less fun.

Documenting your projects

Fritzing is a great tool for documenting your one-off projects. By using real-life representations of components you are not forced to learn and remember abstract symbols. Once created, the pictures of the designs are even beautified! – the program actually 'tidies up' the diagram you create, keeping link wires short and laid out nicely. The design can then be exported as an image, which you would be proud to share by email or on a web blog.

Take the image of one of my most recent projects, in Fig.2. This consists of three components – a microcontroller board, an LCD display and a variable resistor. No matter how hard I try though, it's going to be difficult (if not impossible) for you to re-create the design yourself from this image. Now have a look at a design of similar complexity expressed within Fritzing, in Fig.3. It's clear where the wires go, and you can scroll around and zoom in if necessary. The components are stored within the program in a scalable vector graphic format (.svg), which means they do not loose detail or become pixelated at high zoom factors – see Fig.4. The normal schematic for this design is available if required, as in Fig.5.

Fig.2. Typical breadboard project



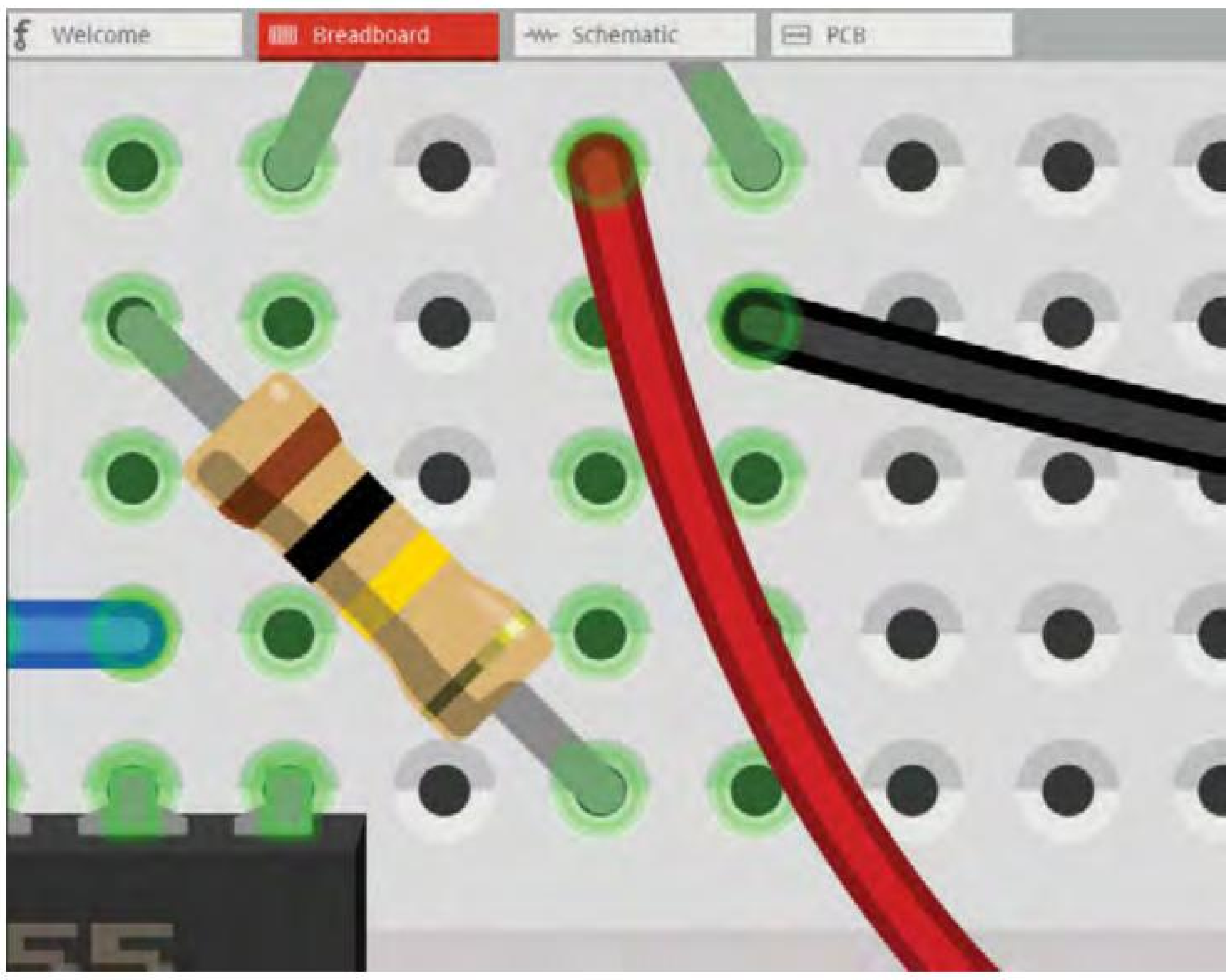


Fig.4. Zooming in

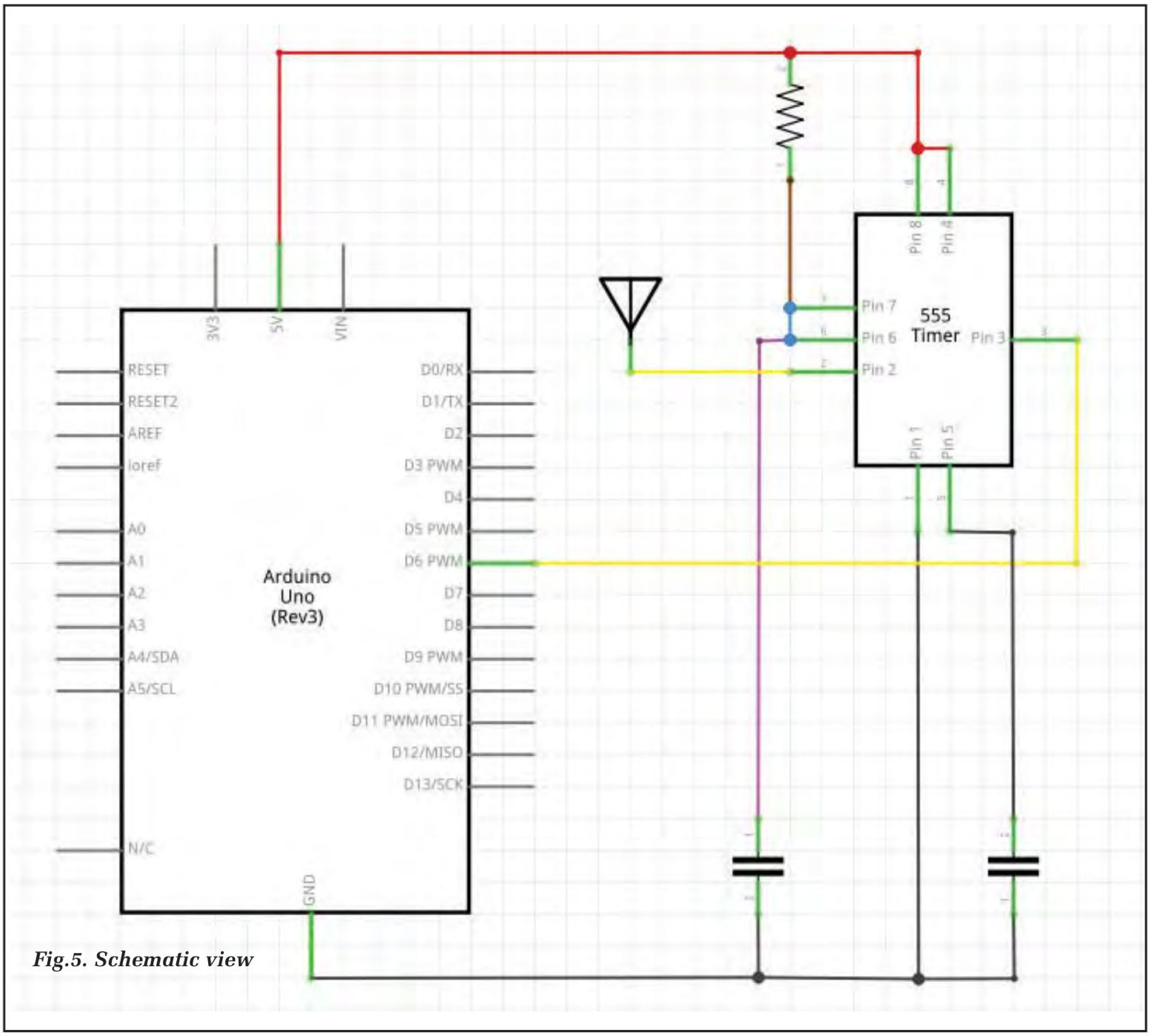
PCB creation

After you have documented your design as a schematic (of sorts) you can switch to one of Fritzing's other design views – PCB – where a printed circuit board can be created. There are no options to automatically place the components, but for simple designs with a few dozen components this is not terribly difficult, and it is something that is learnt by trial and error, either through experimenting or by studying circuits in magazines or on the Internet. What you do get, however, is verification that your components are correctly joined together. It's this kind of 'automatic checking' that makes *any* CAD program valuable. You draw the schematic once, and the program will make sure that all other views of the circuit are consistent with it – and just as important, it will tell you if they are not. The design shown here has been converted to the board layout in Fig.6, where an 'Arduino shield' template is used.

Parts libraries

Fritzing comes with a vast database of 'Parts', not only components but also modules such as the Arduino range and various devices from companies such as Sparkfun. Creating your own parts (I will be making an LPLC board for use in Fritzing) is difficult, but there are plenty of tutorials online to help. Work is in progress to make creating parts easier.

It's a great teaching tool, and designs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D7
D8
D9 PWM
D10 PWM/SS
D11 PWM/MOSI
D12/MISO
D13/SCK
555
Timer
Pin 8
Pin 4
Pin 7
Pin 6
Pin 2
Pin 3
Pin 1
Pin 5

Fig.5. Schematic view

can be exported as high-resolution images suitable for inclusion in webpages or print format – expect some Fritzing images to appear in *PIC n' Mix* soon!

PCB manufacturing service

The Fritzing website offers a number of Ardunio-based kits to help fund the program's development, and they also offer PCB manufacture services.

Their approach is to provide low-cost, low-volume board manufacture by 'batching up' designs from different customers. This results in a longer delivery time, but a relatively low-cost board. They are not the cheapest, but they do offer the easiest route for a complete novice to design and purchase a custom PCB. If you haven't designed a professionally manufactured board before then you should try at least once, but be warned – when you hold your creation in your hands you wont want to leave it at one!

Fritzing can be downloaded from the main support site at **http://fritzing.org**

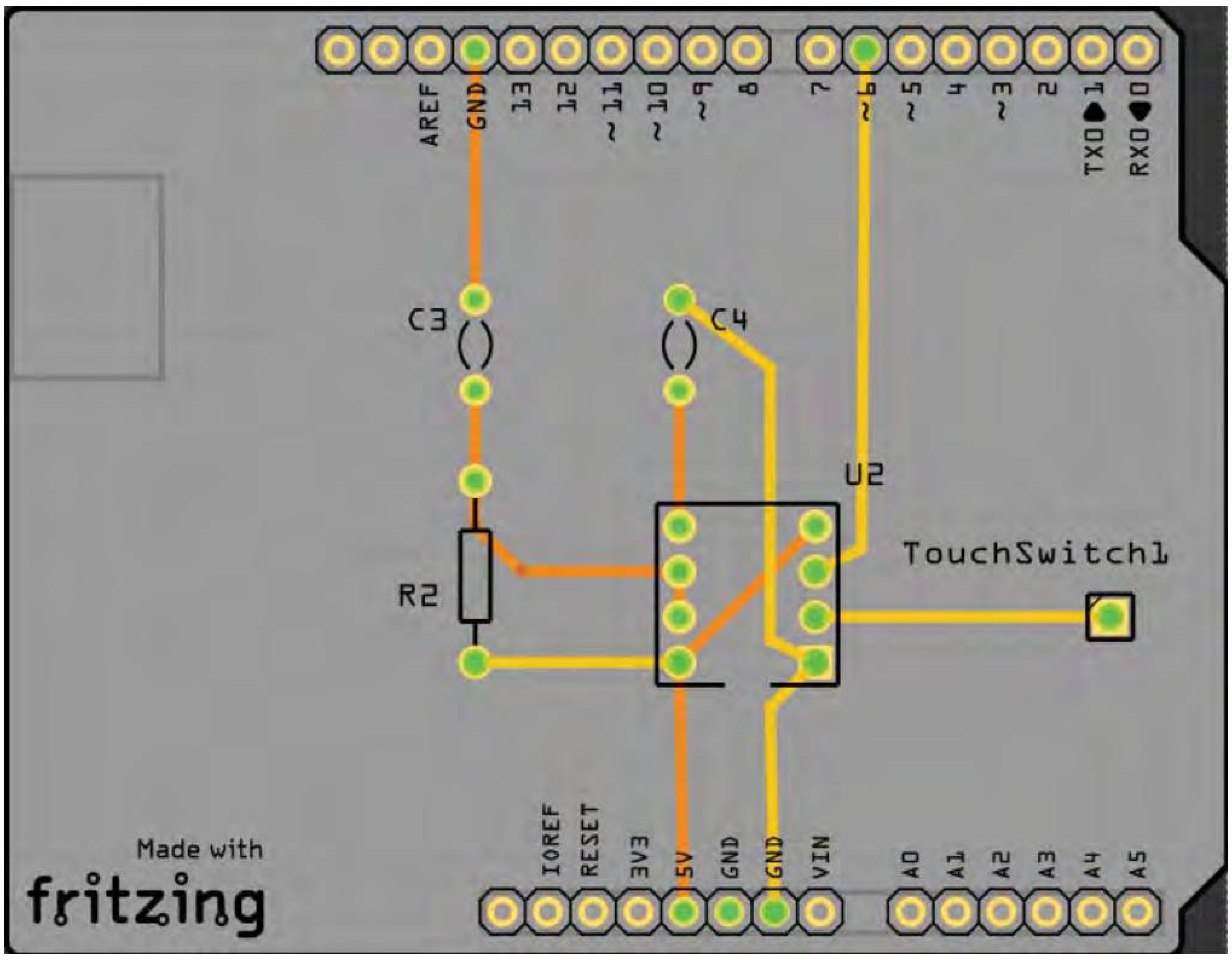
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Fig.6. PCB view

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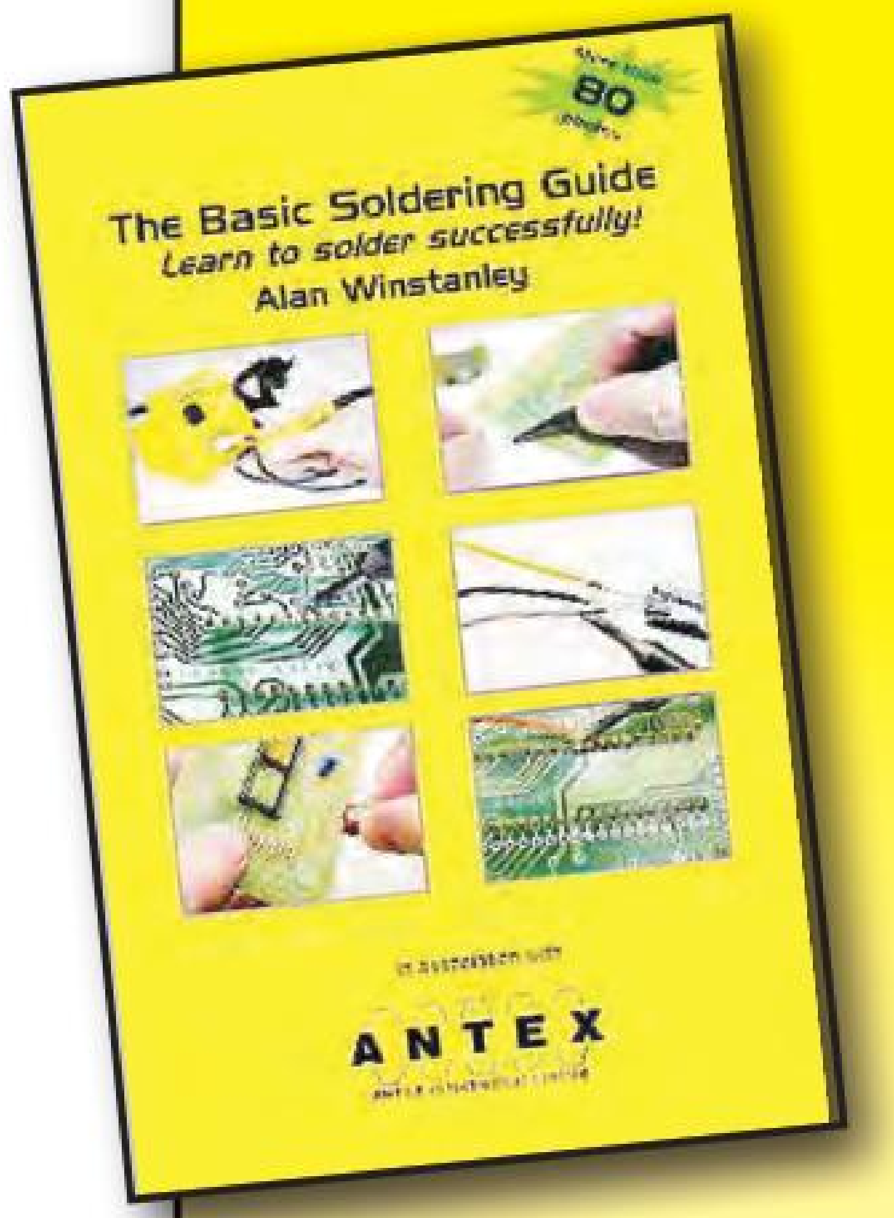

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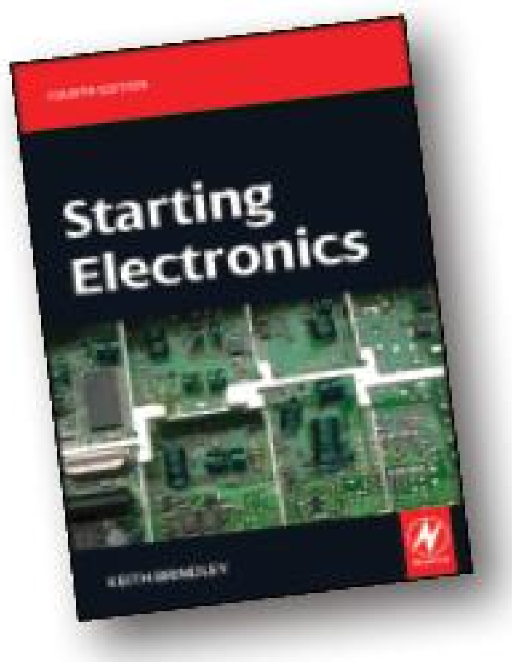

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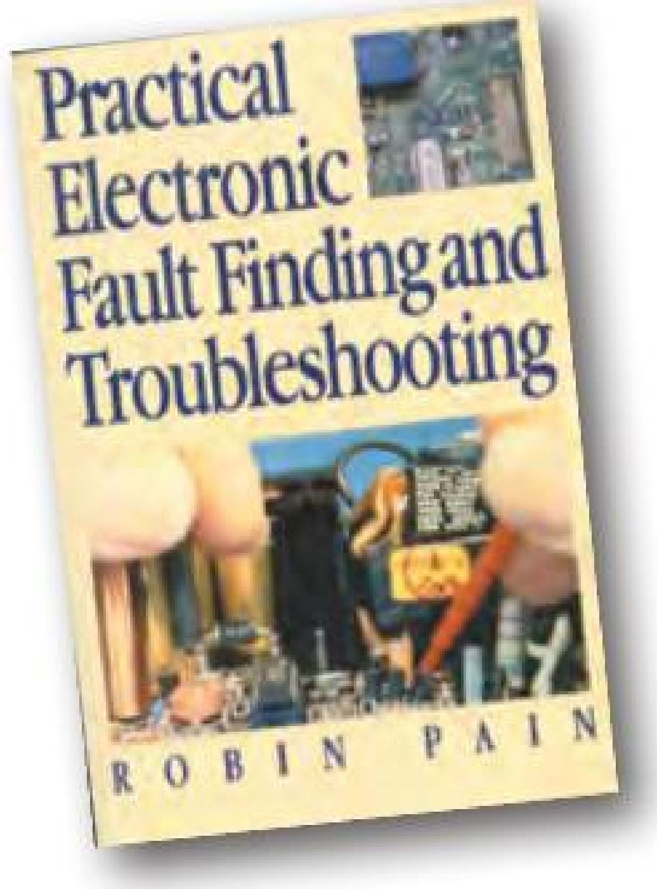

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All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

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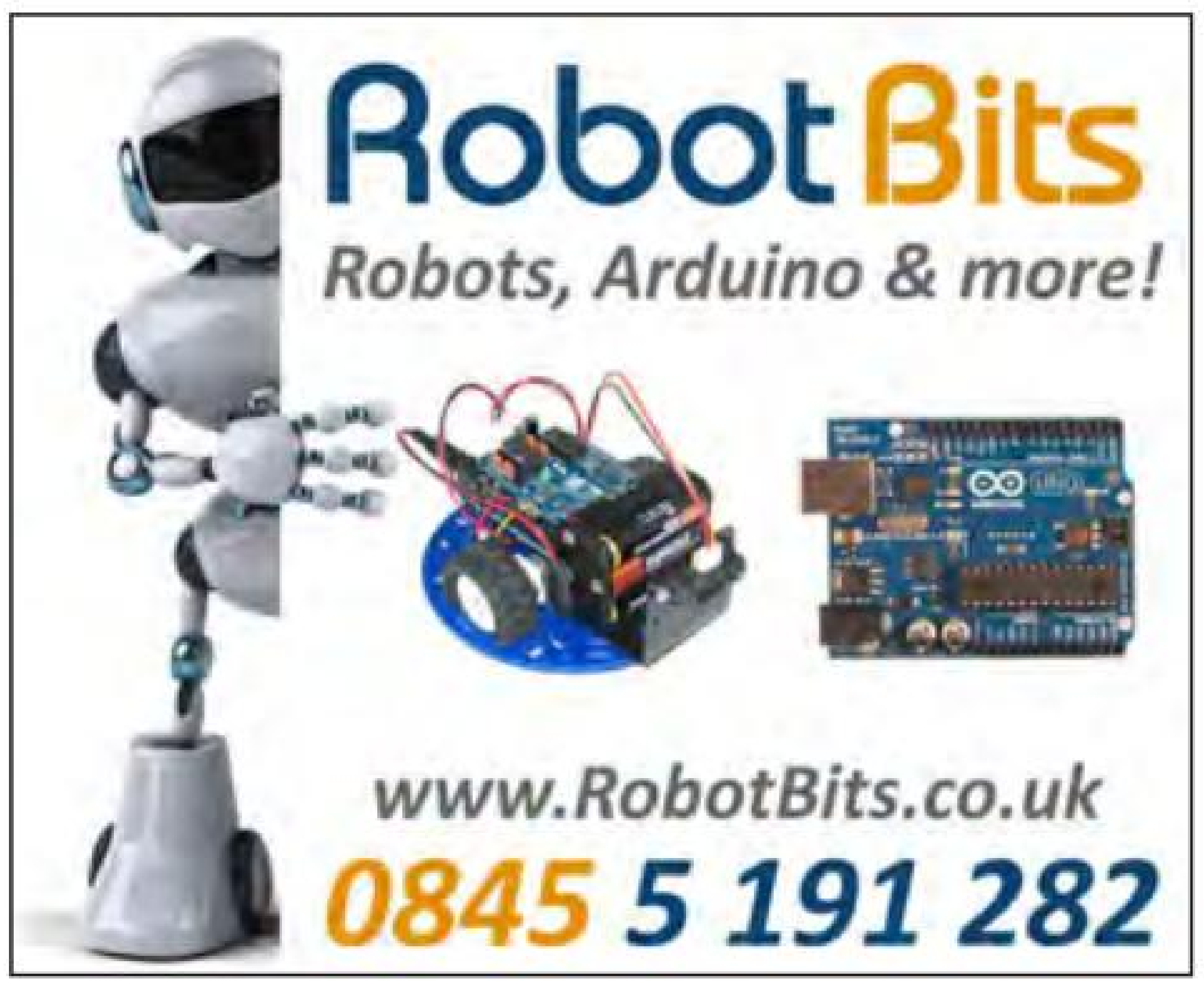

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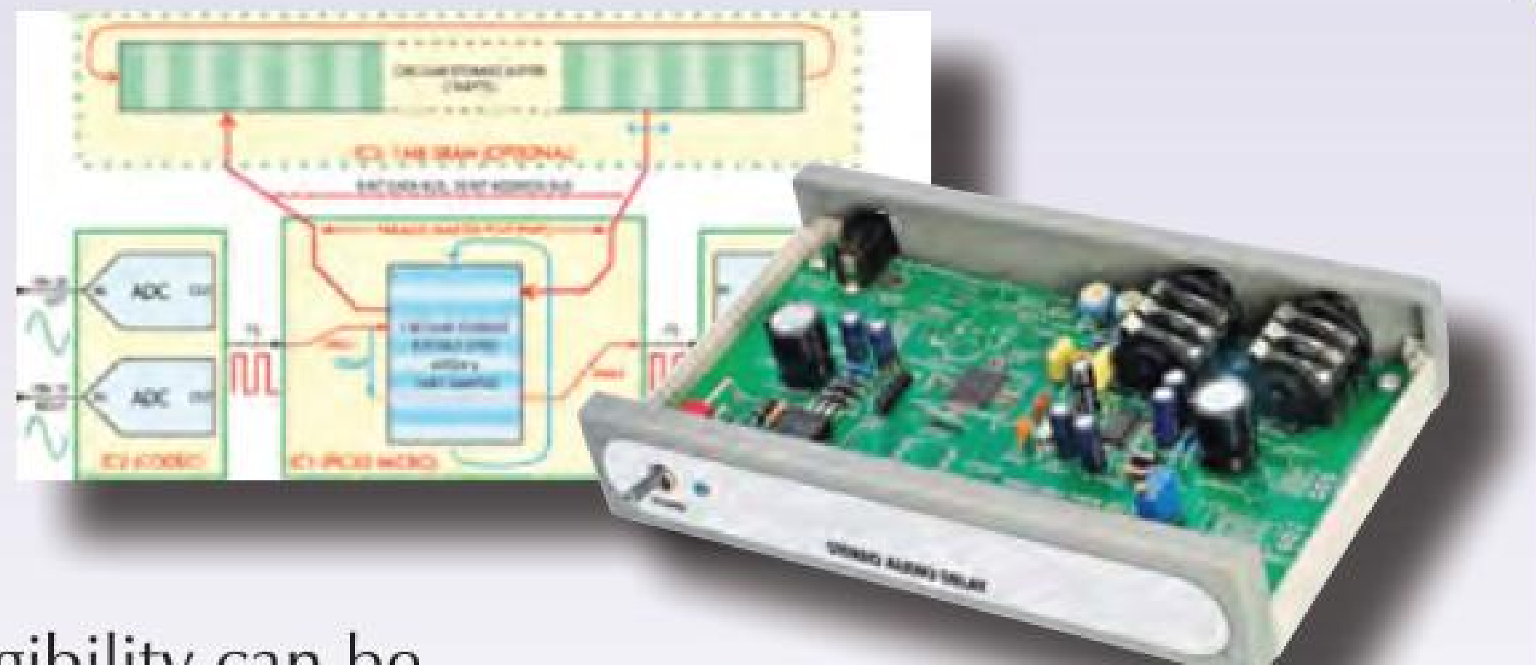

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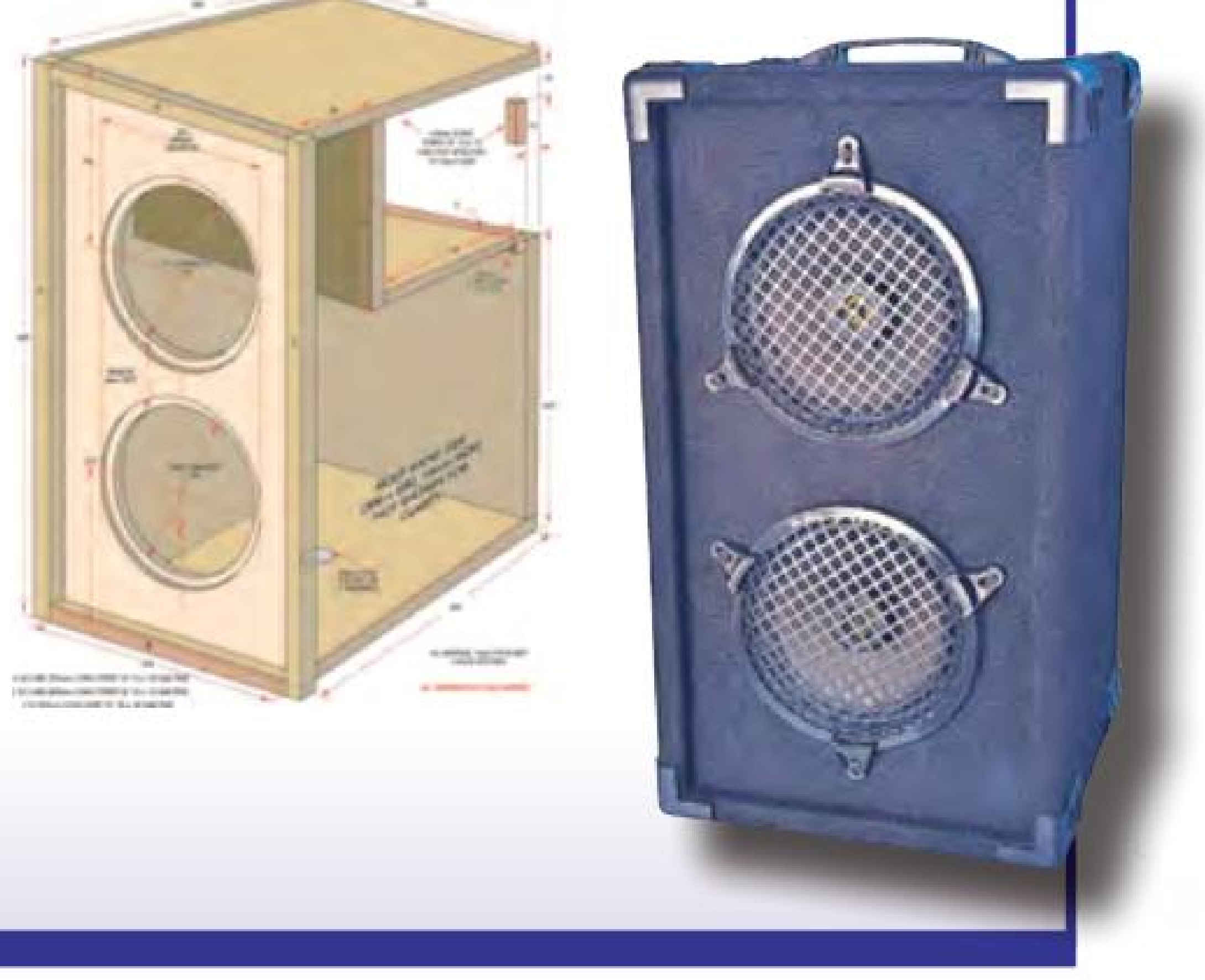
We've finished the electronics module – now it's time to put together the cabinet that houses that module and the two speakers to make loud, beautiful music!



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FEBRUARY '15 ISSUE ON SALE 31 DECEMBER 2014

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